

To: Hughes, Amber[ahughes@blm.gov]
Cc: Staszak, Cynthia[cstaszak@blm.gov]; Matthew Betenson[mbetenso@blm.gov]
From: Titus, Alan
Sent: 2017-05-24T12:34:10-04:00
Importance: Normal
Subject: Re: Kane County RMP review
Received: 2017-05-24T12:34:38-04:00
[10-1-36-3-10-20170214.pdf](#)

Amber,
I've looked at the Kane County Plan. The paleo section under the GSENM Chapter (Page 72, bottom paragraph) is based on pre-MMP documents and is [b] (6) - DPP

[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED].

I didn't see anything else too problematic. If you have questions regarding this, please either email to:

(b)(6) et

or you can text to:

(b)(6) (my wife's phone).

Regards,

On Wed, May 24, 2017 at 8:29 AM, Hughes, Amber <ahughes@blm.gov> wrote:

Hello Team,

As discussed at yesterday's meeting here is a link to the Kane County RMP. Many of you reviewed this document almost a year ago, I included in the 2017 folder the table with your comments from last year.

I placed a new table to record comments for this review. I need to have your comments by COB June 22.

Thank you,
Amber

Z:\Planning\Kane County RMP\March 2017 Review

Amber L Hughes

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"Between stimulus and response there is a space. In that space is our power to
choose our response. In our response lies our growth and freedom" Viktor E
Frankl

--
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GEOLOGY OF THE INTERMOUNTAIN WEST

an open-access journal of the Utah Geological Association

Volume 3

2016

LATE CRETACEOUS STRATIGRAPHY AND VERTEBRATE FAUNAS OF THE MARKAGUNT, PAUNSAUGUNT, AND KAIPAROWITS PLATEAUS, SOUTHERN UTAH

Alan L. Titus, Jeffrey G. Eaton, and Joseph Sertich



A Field Guide Prepared For
SOCIETY OF VERTEBRATE PALEONTOLOGY
Annual Meeting, October 26 – 29, 2016
Grand America Hotel
Salt Lake City, Utah, USA
Post-Meeting Field Trip October 30–November 1, 2016



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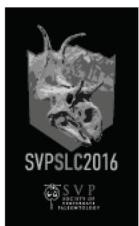
an open-access journal of the Utah Geological Association

Volume 3

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Cover

View looking west over the Blues from the upper view point along Utah SR 12. The lower 400 m of the Upper Cretaceous Kaiparwots Formation is seen from this view as well as the pink and white cliffs of the Paleocene Eocene Claron Formation.



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Late Cretaceous Stratigraphy and Vertebrate Faunas of the Markagunt, Paunsaugunt, and Kaiparowits Plateaus, Southern Utah

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ABSTRACT

The Late Cretaceous succession of southern Utah was deposited in an active foreland basin circa 100 to 70 million years ago. Thick siliciclastic units represent a variety of marine, coastal, and alluvial plain environments, but are dominantly terrestrial, and also highly fossiliferous. Conditions for vertebrate fossil preservation appear to have optimized in alluvial plain settings more distant from the coast, and so in general the locus of good preservation of diverse assemblages shifts eastward through the Late Cretaceous. The Middle and Late Campanian record of the Paunsaugunt and Kaiparowits Plateau regions is especially good, exhibiting common soft tissue preservation, and comparable with that of the contemporaneous Judith River and Belly River Groups to the north. Collectively the Cenomanian through Campanian strata of southern Utah hold one of the most complete single region terrestrial vertebrate fossil records in the world.

INTRODUCTION

The primary purpose of this field trip is to highlight the Late Cretaceous vertebrate paleontology and stratigraphy of southern Utah. This is a daunting task in three days and at best this can only be an overview of what is easily accessible along the road from Cedar City to Escalante (figure 1). The emphasis of this trip is on the terrestrial faunas and facies (figure 2), although the marine Tropic Shale and its fauna will also be examined. There are many other road logs available that highlight broader aspects of the geology of the region and these include Eaton and others (2001), Biek (2014), Knudsen and Biek (2014), and we have borrowed richly from these. This region has also been recently mapped by Biek and others (2015) and we make constant ref-

erence to that exhaustive study. Vertebrate faunal lists for Cretaceous formations and members, organized by plateau, are presented in the appendix.

Overview of Cretaceous Stratigraphy and Vertebrate Paleontology, Southwestern Utah

Upper Cretaceous strata crop out (figure 2) across an almost continuous 210-km-wide band between the Hurricane fault system (west) and the southeast edge of the Kaiparowits Plateau. Scattered outcrops of Late Cretaceous strata also occur west of the Hurricane fault system around the Pine Valley Mountains, Gunlock Reservoir, and Parowan Gap. All of the rock units in these exposures were deposited within the Western Interior

Citation for this article.

Titus, A.L., Eaton, J.G., and Sertich, J., 2016, Late Cretaceous stratigraphy and vertebrate faunas of the Markagunt, Paunsaugunt, and Kaiparowits Plateaus, southern Utah: Geology of the Intermountain West, v. 3, p. 229–291.

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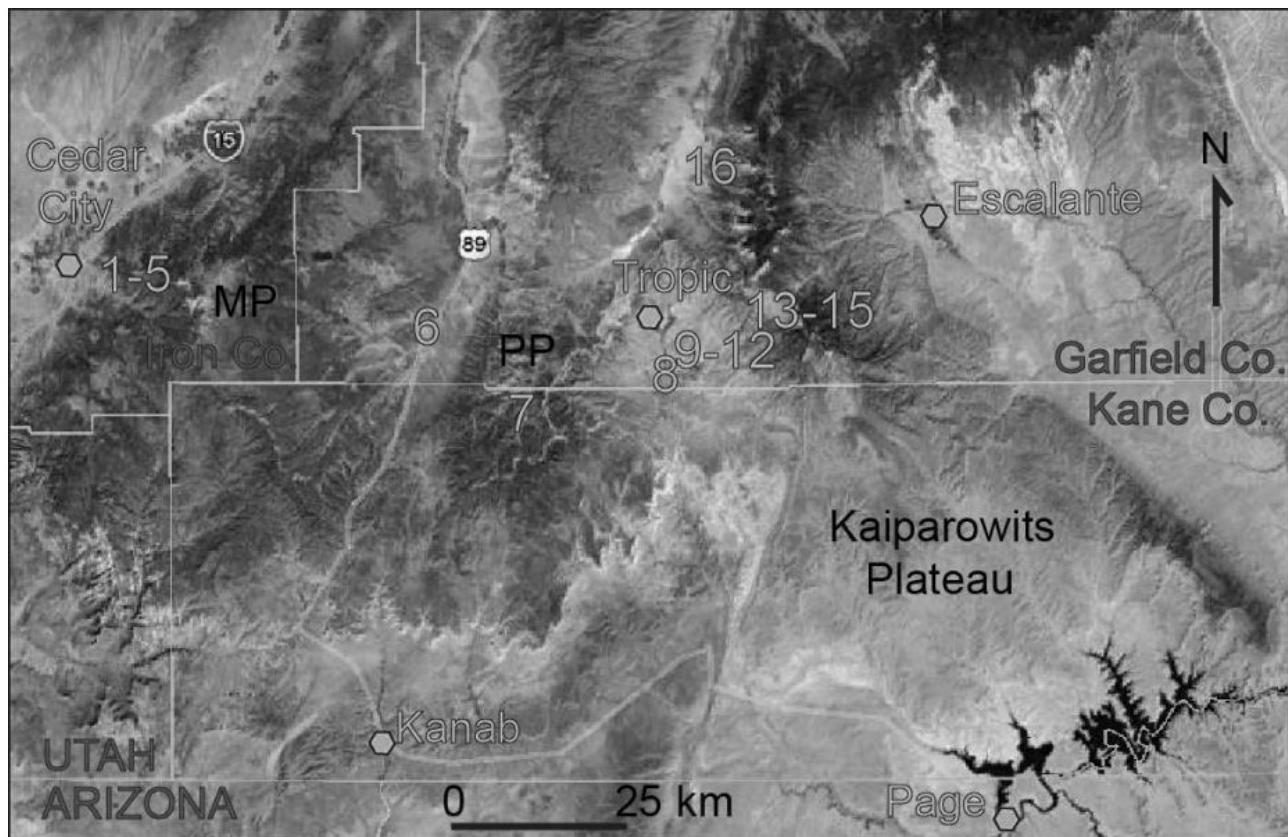


Figure 1. Google Earth image of area covered by this road log. Numbers refer to stops in the road log. MP=Markagunt Plateau, PP=Paunsaugunt Plateau.

basin (figure 3) between late Albian and Maastrichtian time, during the Sevier and early Laramide phases of the North American Cordilleran orogeny (figure 3). As a generalization, the southern Utah Cretaceous section is mostly terrestrial in the western half, and to the east, mixed marine-terrestrial in the lower half and dominantly terrestrial in the upper half (figure 4).

The Cretaceous stratigraphy of the Kaiparowits Plateau, which has become the framework for most of the region, was established by Gregory and Moore (1931), Lawrence (1965), Peterson (1969), and Eaton (1991). The general stratigraphic section is similar throughout the region, but there are some marked facies changes in formations, mostly trending east-west (figure 4).

Paleontological investigations of these outcrops were initiated by the Powell Survey starting in the 1870s. However, during the subsequent 100 years, the region lay largely unnoticed by vertebrate paleontolo-

gists, who were content to work in other, more immediately gratifying, and easily accessed regions. This started to change in the 1970s when crews from the University of Utah and Brigham Young University began prospecting the fossil-rich badlands of the Late Campanian Kaiparowits Formation for vertebrates with good results (Weishampel and Jensen, 1979; DeCourten and Russell, 1985). Soon after, J. Eaton and R. Cifelli began long term collaborative investigations on the microvertebrate faunas of the Kaiparowits Basin (e.g., Cifelli and Eaton, 1987; Cifelli, 1990a, 1990b, 1990c, 1990d; Eaton, 1993a, 1993b, 1995), emphasizing mammalian evolution and biostratigraphy. Eaton and Cifelli were the first researchers to intensively sample the entire Late Cretaceous terrestrial record for vertebrates, and it was their work that led to recognition of the exceptional continuity and quality of the Kaiparowits' vertebrate fossil record. Among other things, the region can claim to yield

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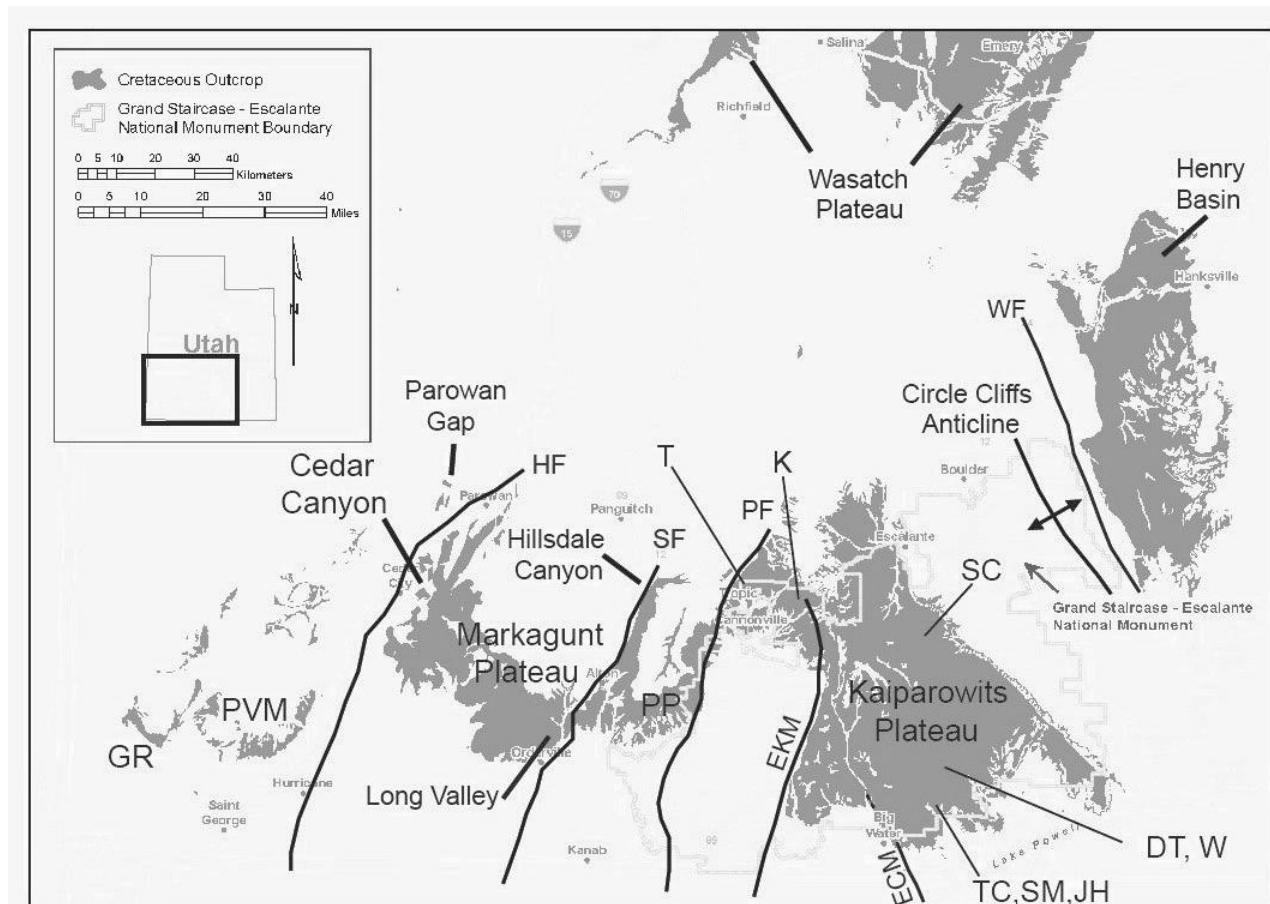


Figure 2. Map showing Cretaceous outcrops in southern Utah. Also shown are major structural features, landforms, location of measured sections, and type sections for the Tropic (T), Straight Cliffs (SC), Wahweap (W), and Kaiparowits (K) Formations and the type sections for the Tibbet Canyon (TC), Smoky Hollow (SH), John Henry (JH), and Drip Tank (DT) Members of the Straight Cliffs Formation. Abbreviations as follows: GR – Gunlock Reservoir; PVM – Pine Valley Mountains; HF – Hurricane fault; SF – Sevier fault; PP – Paunsaugunt Plateau; PF – Paunsaugunt fault; EKM – East Kaibab monocline; ECM – Echo Cliffs monocline; WF – Waterpocket fold. Modified from Titus and others (2013).

diverse terrestrial vertebrate faunas from every stage of the Late Cretaceous except the Maastrichtian. When supplemented by the emerging understanding of the adjacent Paunsaugunt and Markagunt Plateaus, this record becomes truly exceptional, with nearly continuous sampling possible for a 26-million-year time span (ca 100–74 Ma) in facies ranging from shallow marine and coastal plain to alluvial fan (figure 4).

The establishment of Grand Staircase-Escalante National Monument (GSENM) by presidential proclamation on September 18, 1996, led to the need for assessment of condition and significance of all known fossil sites so that a management framework could be

built with the latest and most accurate data. Toward this end, the Monument formed a partnership with the Utah Geological Survey, who initiated field studies in early 1998. One of the results of this work (Foster and others, 2001) was the realization that many areas within GSENM with high potential for fossils had never been adequately surveyed. As a direct result, a key management plan decision was formed that required ongoing annual inventory of geological formations with potential to produce significant fossils (GSENM Management Plan, 2000: PAL-1).

After the Monument Management Plan was put into practice, the Monument-Utah Geological Survey

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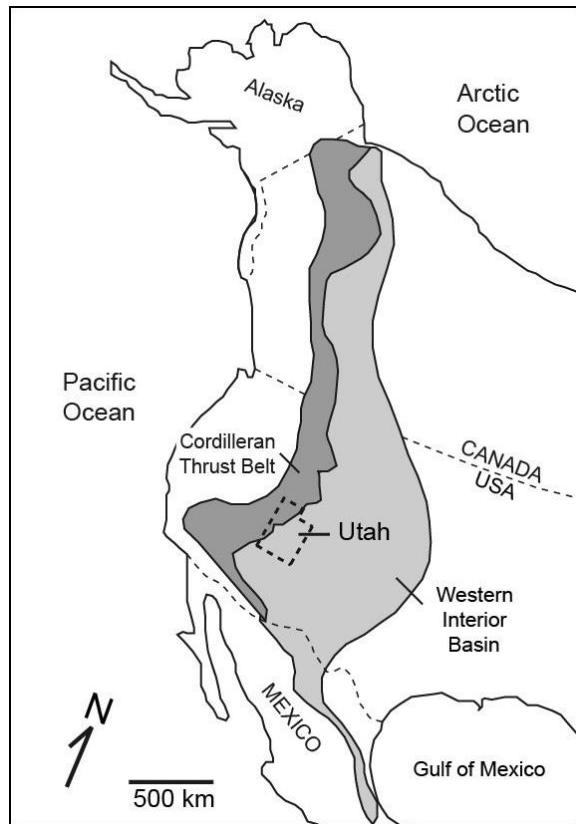


Figure 3. Map showing relationship of the Cordilleran thrust belt (i.e., Sevier fold and thrust belt) with the adjacent Sevier foreland basin or Cretaceous Western Interior basin. From Titus and others (2013).

partnership was expanded to include the Natural History Museum of Utah (NHMU; formerly named the Utah Museum of Natural History [UMNH]) and the Museum of Northern Arizona (MNA) with the intention to intensively survey the Late Cretaceous section of the Kaiparowits Basin region, emphasizing macrovertebrates. A number of articulated or associated specimens of dinosaurs or other macrovertebrates were documented the first year of this effort in 2000. The first new dinosaur taxon named from the Kaiparowits Basin, *Hagryphus giganteus* (Zanno and Sampson, 2005), was based on a partial articulated skeleton of a large oviraptorid collected by the NHMU. Subsequently, 11 other new dinosaur taxa have been named from the Kaiparowits Basin. Intensive recent efforts by the Denver Museum of Nature & Science begun in 2011 have focused largely on the Wahweap and Kaiparowits Formations

underscoring a rare modern model of collaboration between major U.S. institutions (e.g., NHMU, MNA, and others) and GSENM land managers. The marine macrovertebrate record continues to expand as well, with at least five taxa of plesiosaur and a mosasaur (the region's first) discovered and/or published since 1996. Perhaps most importantly, synthesis of the area's outstanding macrofloral record is also underway, which will provide an extremely robust ecological framework within which to place the various vertebrate species. Also occurring in the last 20 years was the expansion of Eaton's original Kaiparowits Plateau work into the Markagunt and Paunsaugunt Plateaus, and the western peripheral outcrops of the Iron Springs Formation (e.g., Eaton, 1999b). The most recent summary of available faunal data for the region's Late Cretaceous succession is found in the 2013 dated Indiana University Press volume "At the Top of the Grand Staircase—The Late Cretaceous of Southern Utah," edited by Titus and Loewen (2013) and much of the appendix is derived from that work.

DAY 1: CRETACEOUS STRATIGRAPHY AND PALEONTOLOGY OF CEDAR CANYON, WESTERN MARKAGUNT PLATEAU

0.0 miles – Set trip odometer to 0 at intersection of State Road (SR) 130 (Main Street) and SR 14 (Center Street), Cedar City.

0.4 miles – Cross the Hurricane fault system. This marks the boundary between the Colorado Plateau to the east and Basin and Range Province to the west. The Lower Triassic Moenkopi Formation is evident here.

0.9 miles – Prominent hogback of the resistant Shinarump Member of the Triassic Chinle Formation.

1.0 miles – Normal fault and lower Chinle strata (purple and gray mudstones) exposed.

1.2 miles – The sequence visible to the north includes the Petrified Forest Member of the Chinle (Upper Triassic), the Dinosaur Canyon Member of the Moenave Formation (Upper Triassic and Lower Jurassic), the Springdale Sandstone Member and main body

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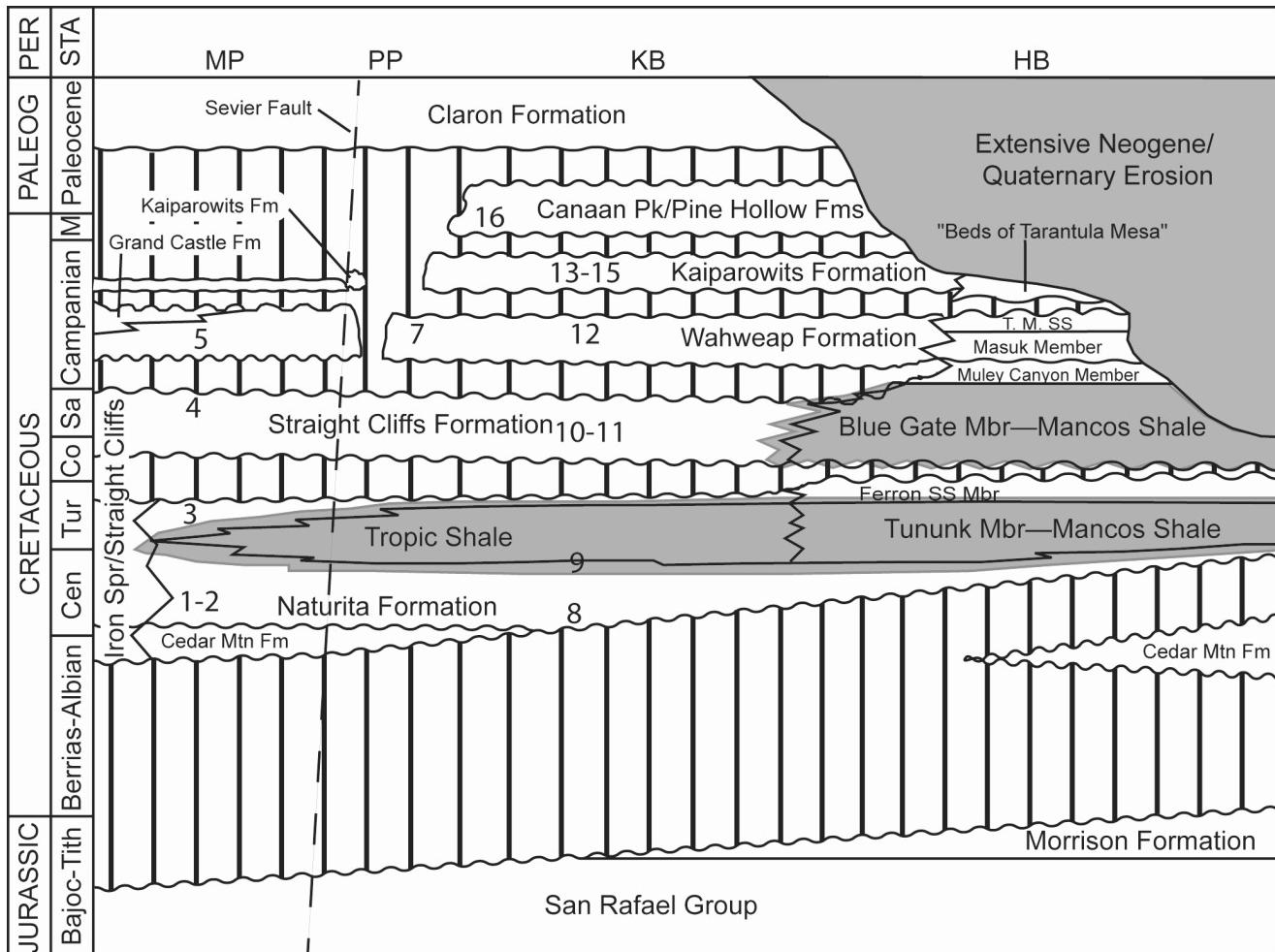


Figure 4. Generalized cross section of Cretaceous rocks covered in this road log showing relative chronostratigraphic relationships and stratigraphic position of field trip stops (numbered). No vertical thickness implied. Blue color indicates marine facies. Abbreviations as follows: PER – Period; PALEOG – Paleogene; STA – Stage; M – Maastrichtian; Sa – Santonian; Co – Coniacian; Tur – Turonian; Cen – Cenomanian; Berrias – Berriasiyan; Bajoc-Tith – Bajocian to Tithonian; T.M. SS – Tarantula Mesa Sandstone; Upp – Upper; Mid-Middle; MP – Markagunt Plateau; PP – Paunsaugunt Plateau; KP – Kaiparowits Plateau; HB – Henry Mountains basin.

of the Kayenta Formation (Lower Jurassic), and the base of the Navajo Sandstone (Lower Jurassic).

1.8 miles – Contact of the Navajo Sandstone and the overlying Co-op Creek Limestone Member of the Carmel Formation (Middle Jurassic).

2.0 miles – Folded and deformed gypsiferous part of Carmel Formation.

3.4 miles – **STOP 1. CEDAR MOUNTAIN, NATURITA (DAKOTA), AND TROPIC FORMATIONS:** In Cedar Canyon, basal Cretaceous beds rest unconformably (figure 5) on the Middle Jurassic Winsor Member of the Carmel Formation (Biek and others, 2015). Previously, the entire Cretaceous section below the Tropic Shale in Cedar Canyon was referred to the Dakota Formation (e.g., Eaton and others, 1999a). However, recent mapping has referred the basal conglomerate and lower 15 to 20 m of variegated, pastel colored smectitic

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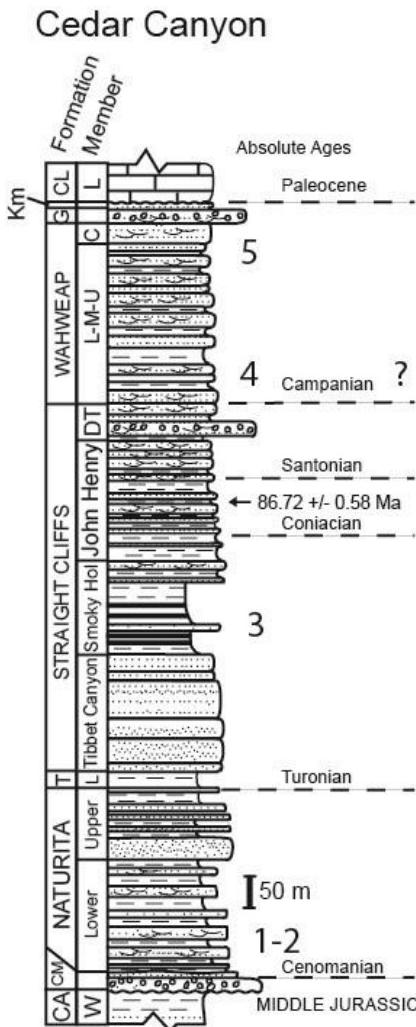


Figure 5. Stratigraphic column for Cretaceous rocks in Cedar Canyon. Numbers correspond with field trip stops in the road log. Abbreviations as follows in ascending order: CA – Carmel; W – Winsor Member; CM – Cedar Mountain; T – Tropic; Smoky Hol – Smoky Hollow; DT – Drip Tank; C – capping sandstone; G – Grand Castle; Km – Cretaceous beds on Markagunt (= lowermost Kaiparowits Formation); CL – Claron; L – Lower; M – Middle; U – Upper.

mudstone (these units are not clearly evident in figure 6), which rests unconformably on the bleached sandstones of the Middle Jurassic Winsor Member of the Carmel Formation, to the Cedar Mountain Formation. The overlying more tan, brown, and gray colored succession is now referred (Kirkland and others, 2016) to the Naturita Formation (figure 6). Dating of the Cedar

Mountain beds in the Markagunt Plateau region has been somewhat problematic; no radiometric ages older than early Cenomanian have been obtained, yet paly-nomorph data suggests a late Albian age (Biek, 2015). Regardless, this interval largely correlates with the Mus-sentuchit Member of the Cedar Mountain Formation in its type area (Kirkland and others, 2016). The Cedar Mountain is overlain by the middle and upper Ceno-manian Naturita Formation (formerly Dakota, [Young, 1960; Carpenter, 2014; Kirkland and others, 2016]) (figures 5 and 6), the lower portion of which is non-marine. The upper portion of the Naturita is paralic and age equivalent to the lower portion of the Tropic Shale in the Kaiparowits Basin. Overall, the Naturita is much thicker in the Markagunt region probably because of higher subsidence rates nearer to the fold and thrust belt. The non-marine part of the Naturita has produced an extensive microvertebrate fauna simply by washing a single road cut (Eaton, 2009, see appendix). Extensive research on the paleontology of the Naturita in this area remains to be done. The marine part of the Naturita Formation in Cedar Canyon has been critical to studies of Milankovitch cycles in the Western Interior Seaway (Laurin and Sageman, 2001, 2007; Tibert and others, 2003) and the Cretaceous anoxic event, OAE 2 (Barclay and others, 2010).

In Cedar Canyon, the Tropic Shale ranges from 0 to 10 m thick. The ammonites *Fagesia catinus* and *Watinoceras* sp. have been found in the formation indicating it is entirely Turonian in age, with the Cenomanian–Turonian boundary occurring essential-ly just below its base (Eaton and others, 1999a; Tibert and others, 2003). The Tropic fauna by volume consists mostly of inoceramid bivalves and other mollusks. Shark teeth or other vertebrate remains are rather rare and no reptilian fauna has been reported, although tur-tle remains are found in the underlying paralic portion of the upper Naturita Formation associated with oysters and other brackish water mollusks (Joyce and others, 2016).

5.4 miles – Maple Canyon to the north. Detailed studies of the brackish to marine history of the upper Naturita Formation, the very thin Tropic Shale, and the Tibbet Canyon Member of the Straight Cliffs Formation

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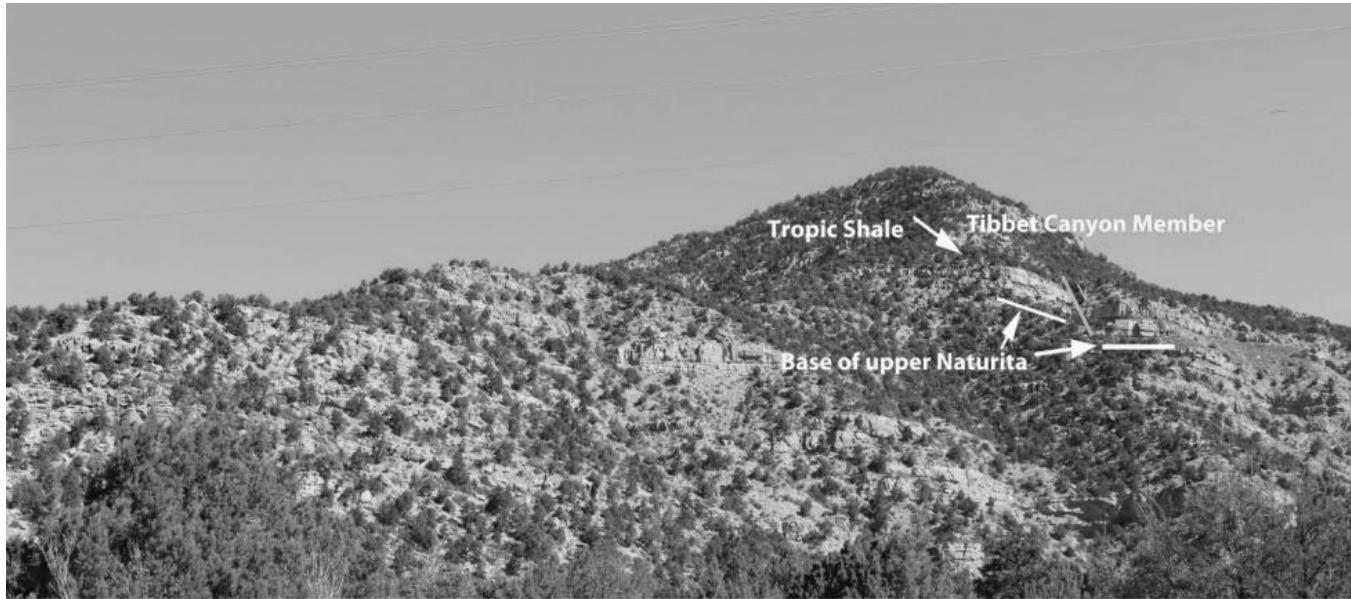


Figure 6. Looking north at Naturita (Dakota) – Tibbet Canyon Member section. Annotated by Jiri Laurin (Institute for Geophysics at the Czech Academy of Sciences).

has been undertaken here by Eaton and others (2001), Laurin and Sagemen (2001, 2007), and Tibert and others (2003).

5.8 miles – **STOP 2.** UMNH VP LOCALITY 162: Outcrops in this road cut have yielded microvertebrates, including mammals (faunal list in appendix; figure 7), through blind washing methods (Eaton, 2009). The mammalian fauna here includes a multituberculate (*Dakotamys malcolmi*) that is identical to the taxon recovered from late Cenomanian UMNH VP locality 27 on Bulldog Bench along the eastern margin of the Paunsaugunt Plateau. However, *Eoalphadon woodburnei* (figure 8) appears distinctly more primitive than species of *Eoalphadon* recovered from UMNH VP locality 27 and may suggest that the Naturita Formation here could be slightly older than the fauna from Bulldog Bench, possibly middle Cenomanian.

6.3 miles – Normal fault brings the Tibbet Canyon Member to the road level.

6.9 miles – After crossing bridge to the right, outcrop exposes Tibbet Canyon Member against coal and

mudstone beds of the Naturita Formation.

8.1 miles – Contact between Tropic Shale and vertical outcrops of the Tibbet Canyon Member of the Straight Cliffs Formation (figure 9) in road cut. The Tropic Shale is overlain by a very thick (190 m) section of late early to middle Turonian Tibbet Canyon. This marine to marginal marine section and contains abundant brackish and marine mollusks (Eaton and others, 2001).

10.2 miles – Contact between the Tibbet Canyon Member and the basal coal beds of what we have identified as Smoky Hollow Member. See discussion in Stop 3 about identification, correlation, and nomenclature of the members of the Straight Cliffs Formation.

10.6 miles (just past milepost 11) – **STOP 3.** STRAIGHT CLIFFS FORMATION: In general, recognizing the standard four members of the Straight Cliffs Formation in the Markagunt region is difficult, as compared to the type sections in the Kaiparowits Plateau (figure 2). As Biek and others (2015) have done the most recent and extensive fieldwork in the region,

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Figure 7. Looking across SR 14 at lower Naturita (Dakota) Formation (UMNH VP locality 162).

we are following their terminology. In general, here the Tibbet Canyon Member, the lower portion of which is age equivalent to the upper portion of the Tropic Shale in the Kaiparowits region, is much thicker, and the John Henry Member in the Markagunt has almost none of the paralic character seen at its type section; more closely resembling the Iron Springs Formation.

At this stop, the base of the Smoky Hollow Member contains common brackish water gastropods described by Hoffman (2005; locality “Jeff’s Snail Slope”). Many of these gastropods are identical to those found in the lower Smoky Hollow Member along SR 12 at the east side of the Paunsaugunt Plateau in Bryce Canyon National Park (the Glory Cove fauna). The brackish water invertebrate fauna here is mostly mollusks, but foraminifera and ostracods have been recovered from just above the Tibbet Canyon Member (UMNH VP locality 66) just west of the Southern Utah University (SUU) center. Hoffman (2005) considered the gastropod fauna to be late middle Turonian. At UMNH VP locality 66,

very low in the Smoky Hollow Member, abundant rhinobatoid teeth and other fish teeth have been recovered (Eaton and others, 1999). The Smoky Hollow brackish section here is 54 m thick, much thicker than on the Kaiparowits Plateau indicating that subsidence rates are still higher in the Markagunt Plateau area (Eaton and others, 1999). The remaining upper part of the Smoky Hollow Member (53 m) consists of fluvial channel and floodplain deposits. No fossils have yet been recovered from the upper fluvial sequence.

The John Henry Member here consists of variegated floodplain deposits and meandering river sandstones. In its type area, the Smoky Hollow Member is usually capped by a distinctive thick and laterally continuous conglomerate referred to as the Calico bed. Overlying the Calico is the base of the John Henry. In the Markagunt Plateau, locally there is a sandy discontinuous conglomeratic unit 107 m above the base of the Smoky Hollow that may be an equivalent to the Calico bed. Unfortunately, since it is discontinuous in the Cedar

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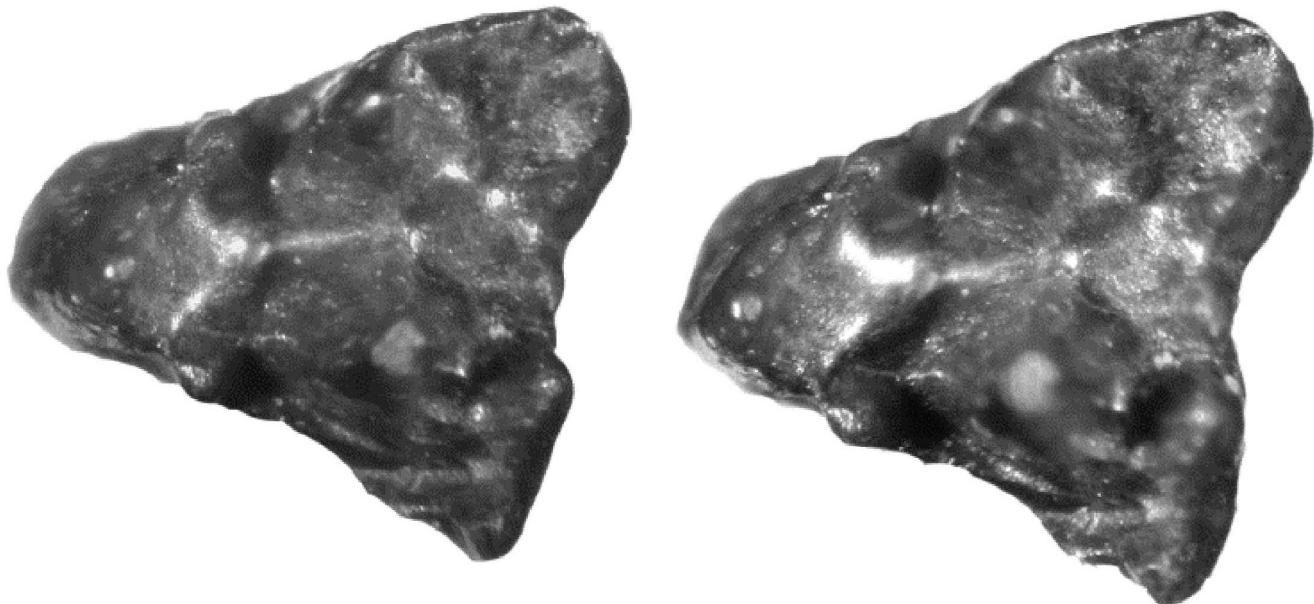


Figure 8. Stereo pair photo of a specimen of the metatherian *Eoalphadon woodburnei* recovered from UMNH VP locality 162. Specimen is approximately 3 mm in horizontal length.

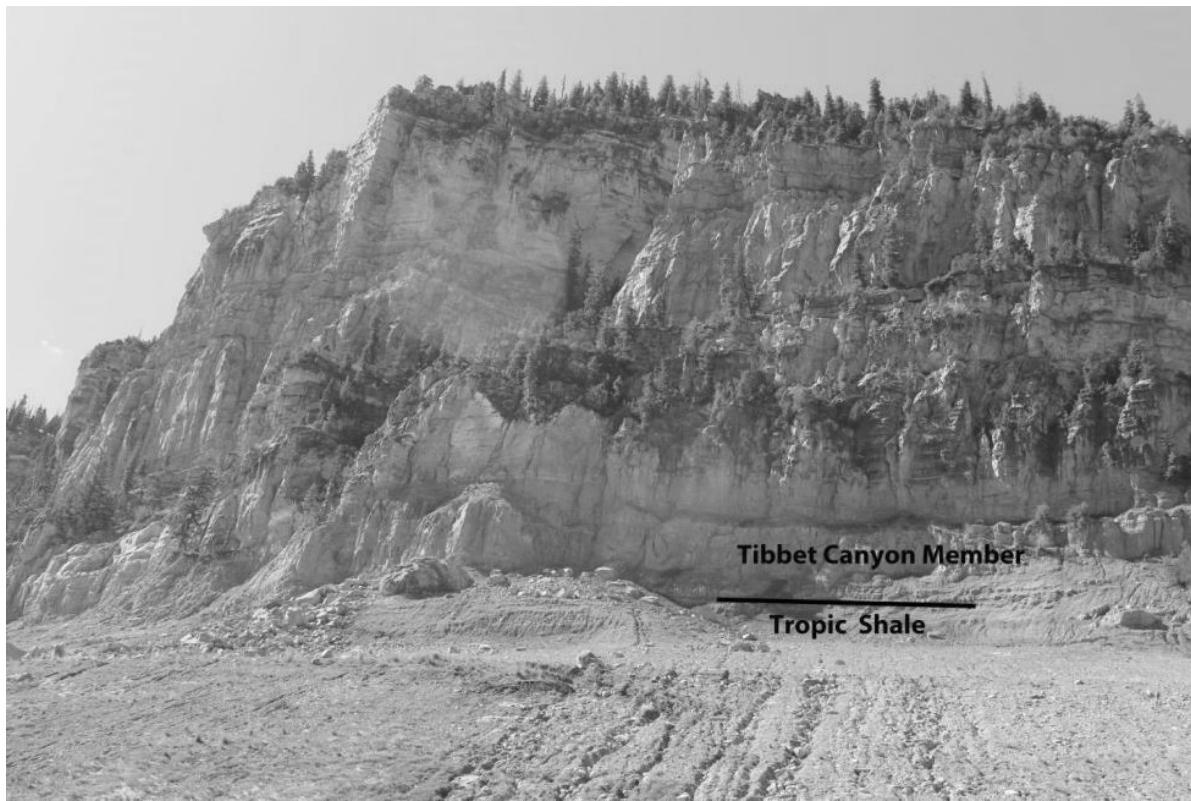


Figure 9. Contact of Tropic Shale and the Tibbet Canyon Member on south side of road in landslide area along SR 14.

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Canyon area, the boundary between the two members can be difficult to recognize.

The road on SUU property across from the center leads to ridges that have much better exposures of the Straight Cliffs Formation than is seen in Cedar Canyon. There, localities provide important age controls on the section, including UMNH VP localities 8 and 9 (vertebrate faunal list in appendix). Well above the base (115 m and 150 m, respectively) of the John Henry Member are two localities, UMNH VP 9 and UMNH VP 8 (Eaton and others, 1999, 2001; Eaton, 2006a). Both of these lie well below a horizon with an $^{40}\text{Ar}/^{39}\text{Ar}$ date, taken on euhedral biotite, of 86.72 ± 0.58 Ma (Eaton and others, 1999) corrected to 87.28 Ma in Albright and Titus (2016), suggesting a Coniacian (or older) age for these localities (see faunal lists in appendix). UMNH VP locality 8 contains abundant freshwater sharks which may represent the Coniacian transgression. These are the only freshwater sharks or rays found in the entire section in Cedar Canyon. No age-diagnostic fossils have yet been recovered above the horizon with the radiometric date and below the Drip Tank Member in which the age of the John Henry Member would presumably be Santonian. UMNH VP locality 9, the stratigraphically lowest vertebrate locality has produced a small fauna that includes marsupial and multituberculate teeth, but the producing horizon has never been located (Eaton, 2006a). UMNH VP locality 8 contains abundant freshwater shark teeth and rare mammalian specimens including the multituberculate *Cedarmys* and fragments of eutherian molars (Eaton, 2006a). Much more work needs to be done on these localities as well as prospecting for additional localities.

The uppermost member of the Straight Cliffs Formation is the Drip Tank Member (Santonian, see Albright and Titus, 2016) on the Kaiparowits Plateau (Peterson, 1969). Moore and Straub (2001) suggested that a conglomerate found 457 m above the top of the Tibbet Canyon Member is the Drip Tank Member. Along SR 14 in Cedar Canyon, this conglomerate is only a few meters thick and Eaton (in Eaton and others, 2001, figure 5) placed a question mark next to the Drip Tank in the stratigraphic column. Biek and others (2015) indicate the same conglomerate is 30 m thick just to the south. Edward Sable (U.S. Geological Survey, written

communication, 1994), Moore and Straub (2001), and Biek (2015) claimed to have traced the unit around the southern margin of the plateau to Long Valley where they correlate it with what was previously referred to as the lower member of the Grand Castle Formation.

10.9 miles – A conglomerate that crops out on the north side of the road (as much as 12 m thick) is thought to possibly represent the Calico bed, but identification/correlation is uncertain because it is not laterally continuous.

12.6 miles – Typical outcrops of John Henry Member equivalent rocks are in the road cuts. Notes these include variegated mudstone and thin sandstone; however, in this area, the section is dominated by mudstone. Macrovertebrate remains are known from the John Henry on the Markagunt Plateau, and a partial, small articulated coelurosaur-grade theropod was recovered from north of Cedar Canyon many years ago. This specimen remains undescribed. If the outcrops were more extensive, it is likely that macrovertebrate remains would be found much more frequently.

12.8 miles – Outcrop of a thin pebbly conglomerate considered to represent the Drip Tank Member (see discussion under STOP 3 above). This conglomerate does appear to be laterally continuous and is thicker elsewhere. Biek and others (2015) consider this sandstone to be equivalent to the lower conglomeratic member of the Grand Castle Formation in Parowan Canyon.

13.0 miles – **STOP 4. LOWER WAHWEAP FORMATION-UMNH VP LOCALITY 10:** Drive a short distance and walk down to UMNH VP locality 10 (figure 10). UMNH VP locality 10 (see faunal list in appendix) is located 21 m above the Drip Tank conglomerate. The site contains some taxa (see appendix) similar to those previously recovered from the Santonian part of the John Henry Member (*Cimolomys* sp.) or the Santonian Milk River Formation of Canada (*Picopsis* sp.) (Eaton, 2006a). One taxon (*Cimolodon similis*) has been recovered both from the Milk River and the Wahweap Formations and two taxa (*Symmetrodontoides* sp. cf. *S. foxi* and *Cimolodon* sp. cf. *C. nitidus*) are almost iden-

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Figure 10. Josep San Juan Girbau (American University, Beirut) at UMNH VP locality 10.

tical to those recovered from the Wahweap Formation (Eaton, 2006a). This suggests a fauna transitional between that of the John Henry Member and the Wahweap Formation. However, based on stratigraphic correlation this locality is most likely late early Campanian. The Wahweap in the type area has thick laterally accreted sandstone bodies and drab organic-rich floodplain mudstone beds (Eaton, 1991). The sequence above the Drip Tank Member in Cedar Canyon is 290 m thick and is dominated by variegated light-colored mudstone and isolated sandstone bodies representing meandering rivers (Eaton and others, 2001); as is much of the section beneath the Drip Tank Member in Cedar Canyon. For this reason (and others discussed below) Eaton and others (2001, figure 5) placed a question mark next to Wahweap in the stratigraphic column. To emphasize the uncertain identification, Eaton has sometimes applied the term “Formation of Cedar Canyon” (e.g., Roček and others, 2013, figure 12.3) for this part of the stratigraphic section. Titus and others (2013, figure 2.7) considered this part of the section to represent the John Henry Member of the Straight Cliffs Formation. The interpretation of Biek and others (2015) for the upper portion of the Cretaceous sections is followed here. $^{40}\text{Ar}/^{39}\text{Ar}$ dates of 80.6 and 79.9 Ma (Jinnah and others, 2009; Jinnah, 2013) from low in the Wahweap Formation on the Kaiparowits Plateau and paleomagnetic sections from

the formation (Albright and Titus, 2016) indicate that in the Kaiparowits Plateau region there is a significant unconformity between the Drip Tank Member and the overlying Wahweap Formation such that strata of the lower Campanian are missing. If the unit in Cedar Canyon is actually a western equivalent of the Wahweap, perhaps the lower Campanian strata are present in this area. Future research involving radiometric dating and paleomagnetic studies would be most helpful in resolving this issue.

0.0 miles (restart mileage).

1.0 miles – Note fine-grained variegated mudstone beds of the Wahweap Formation, which are essentially indistinguishable from those of the John Henry Member in Cedar Canyon.

1.3 miles – Turnoff to Webster Flats. Here the white sandstone (figure 11) is considered to represent the capping sandstone member (as defined by Eaton, 1991) of the Wahweap Formation used by Pollock (1999) and Lawton and others (2003), but this interpretation is not universal (see discussion below under STOP 5). The sandstone consists largely of reworked Navajo Sandstone. It has not yielded any identifiable vertebrate fossils but does contain the molds of plant material in iron concretions and on bedding planes.

1.4 miles – **STOP 5. UMNH VP LOCALITY 11:** This locality lies at the very top of the Wahweap Formation in Cedar Canyon (267 m above UMNH VP locality 10, Eaton, 2006a). It has a very enigmatic fauna with “pediomysids” similar to those of the Santonian Milk River Formation but also with a taxon (*Meniscoessus* sp. cf. *M. intermedius*) closer to known taxa of the Wahweap Formation or even Judithian faunas. The locality also contains an anuran (*Nezpercius dodsoni*) that has only been recovered in southwestern Utah from the Wahweap (Gardner and Demar, 2013). High in the Cretaceous section above the Wahweap, Nichols (1977) reported the recovery of no palynomorphs younger than Santonian, which supports the interpretation of Titus and others (2013); however, Lawton and others (2003) reported a distinctly middle Campanian paly-

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Figure 11. Capping sandstone member of the Wahweap Formation, Websters Flat turnoff.

nomorph (*Dyadonapites reticulatus*) from the capping sandstone member at the Webster Flat exposures (see below) and this is the probable age for these beds.

The about 60-m-thick quartz arenite sandstone, exposed at the Webster Flat turnoff from SR 14 (mile 1.3), lies immediately above the variegated floodplain deposits of the Wahweap Formation containing UMNH VP locality 11. This unit has been variously referred to the Kaiparowits(?) Formation (Moore and Straub, 2001), the middle member of the Grand Castle Formation (Goldstrand, 1991, 1992) and the capping sandstone member of the Wahweap Formation (Pollock, 1999; Lawton and others, 2003). Eaton and others (2001) used the noncommittal term “white sandstone” for this sandstone body. We are in agreement with Biek and others (2015) that this unit is indeed the capping sandstone member of the Wahweap Formation.

The complexity of this area of been recently exam-

ined during mapping of the region by Biek and others (2015). This mapping necessarily involved trying to resolve the complex relationship between outcrops in Cedar Canyon and those in Parowan Canyon, which is the next major canyon 20 to 30 km to the north. Parowan Canyon is floored by a Cretaceous sequence of tabular sandstone beds separated by thin mudstone beds previously mapped as Iron Springs Formation (mapping that Eaton still thinks was correct) that has now been mapped as John Henry Member of the Straight Cliffs Formation in Biek and others (2015). Two localities, UMNH VP 6 and VP 64 (Eaton and others, 2001, figure 5) are known from the Iron Springs/John Henry Member of Parowan Canyon, and although UMNH VP 64 was relatively rich in non-mammalian vertebrates none of those specimens have yet been described.

Overlying the Iron Springs/John Henry Member in Parowan Canyon is the Grand Castle Formation of

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Figure 12. UMNH VP locality 11, upper Wahweap Formation below the capping sandstone member.

Goldstrand (1991, 1992) and Goldstrand and Mullett (1997). It rests on a deeply weathered surface on top of the Iron Springs/John Henry Member, enough of an unconformity that Goldstrand (1991, 1992) and Goldstrand and Mullett (1997) suggested a Paleogene age for the Grand Castle. The Grand Castle Formation was originally divided into three members. The middle sandstone member of the Grand Castle was shown to be Cretaceous by the discovery of dinosaur tracks by Hunt and others (2011) and palynomorphs reported by Biek and others (2015). The underlying lower conglomeratic member of the Grand Castle has been correlated in Biek and others (2015) to the Drip Tank Member in Cedar Canyon and assigned to that member. Biek and others (2015) correlated the few tens of meters of the lower middle sandstone member of the Grand Castle Formation in Parowan Canyon 20 km away to the 290 m of the Wahweap Formation underlying the capping sandstone member (figure 12) and the rest of the middle member directly to the capping sandstone member. This represents a remarkable thickening of capping sandstone member (formerly, the middle member of the Grand Castle Formation) from Parowan Canyon to Cedar Canyon, whereas the lower unit thins from 30 to 41 m or less. This geometric problem has not been resolved and much more work needs to be done on the relationships of the Cretaceous sequence in Parowan and Cedar Canyons.

0.0 miles – restart mileage.

0.7 to 0.8 miles – Still traveling in the capping sandstone. Upper portion of this mapped unit here contains poorly exposed pebble and cobble conglomerates that are similar to those observed at the top of the capping sandstone member of the Wahweap Formation in the western Paunsaugunt Plateau (Hillsdale Canyon) and represent distal equivalents of the Grand Castle Formation. The Grand Castle as now defined is about 55 m thick in Parowan Canyon and thins into Cedar Canyon where it is variable in thickness from 0 to 8 m.

1.1 to 1.3 miles – Road cuts are in a unit (as much as 60 m thick) that Biek and others (2015) mapped as “Km” (Cretaceous strata on the Markagunt Plateau). This series of sandstone, mudstone, and siltstone beds overlie the coarse conglomeratic facies at the top of the capping sandstone member of the Wahweap Formation and underlies the base of the Claron Formation (Paleogene). Importantly, this interval contains abundant black chert lithics and minor feldspar, which are virtually absent in the underlying capping sandstone member. Biek and others (2015) state (p. 151) that “the stratigraphic position of the Km unit precludes it being Santonian in age.” We agree even though Nichols (1977) reported Santonian palynomorphs from this same interval. Biek and others (2015) reassessed the palynomorphs from the Km beds and reported late Campanian to Maastrichtian taxa, which agrees better with the current lithostratigraphic correlations. A very similar interval was mapped by Biek and others (2015) above the capping sandstone member of the Wahweap Formation in Hillsdale Canyon on the west side of the Paunsaugunt Plateau as Kwcg (pebbly sandstone unit of the Wahweap above the capping sandstone) and Kkl (lower unit of the Kaiparowits Formation—see Biek and others, 2015; figure 28, in which Kwu Kkl). These are mostly likely facies variations within the lower Kaiparowits depositional system that arise where approaching the thrust belt and expanding the section.

1.4 miles – Basal Claron Formation (Eocene) in road cut.

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3.5 miles – Intersection with SR 148 to Cedar Breaks.

5.7 miles – Cinder cone and basalts of the Markagunt Plateau volcanic field which erupted from latest Pliocene through the Pleistocene and possibly into the Holocene (Johnson and others, 2010).

9.0 miles – Claron Formation to left and Navajo Lake to the right which formed as a result of basalts damming the drainage.

19.2 miles – Claron Formation outcrops which contain abundant trace fossils described in Bown and others (1997).

21.7 miles – Short Canyon turnoff.

22.3 miles – Mile 38 sign post.

22.7 miles – Outcrop to right is the basal Brian Head Formation (late Eocene). This blind wash locality (UMNH VP locality 1085, IP locality 186) has produced rodent teeth, ostracods, ray teeth, and miscellaneous fragments of fish. Initially, this locality was thought to be part of the Claron Formation by Eaton and others (2011) and they reported the mammals and ostracods from this locality to be from the Claron Formation. Subsequent location of a thin pebble conglomerate (the Boat Mesa Conglomerate) below this white unit demonstrates that it is instead part of the Brian Head Formation and not the Claron.

23.0 miles – Claron outcrop in road cut.

23.3 miles – Outcrops of Brian Head Formation (figure 13).

23.4 miles – Claron Formation. The lithology of the Claron in this area is unusual with abundant fine-grained, soft, pastel-colored beds of brown quartzose sandstone, and white carbonate beds. These lithologies are exposed for the next 16 km northward on U.S. Highway 89. The only bone fragments recovered from the Claron Formation anywhere are from these outcrops of brown sandstone.

25.1 miles – Junction SR 14 and US 89, Long Valley Junction. Driving north from the junction, the upper part of the Claron Formation is exposed in the road cuts.

34.5 miles – Driving on top of the Claron Formation, hills above the white carbonate are made of the lower Brian Head Formation.

35.5 miles – STOP 6. OVERVIEW OF THE PAUNSAUGUNT PLATEAU: To the east is the western margin of the Paunsaugunt Plateau. The Sevier normal fault exposes the Cretaceous section consisting of the upper Straight Cliffs and Wahweap Formations. Here, the John Henry Member consists dominantly of fluvial sandstone with almost no mudstone. This Cretaceous block is separated from the Claron Formation to the east by another fault, the Sand Pass fault. These faults merge just south of Hillsdale Canyon (major canyon to the north) where overlying the capping sandstone member (figure 14) of the Wahweap Formation, Biek and others (2015) delineated the following succession: Kwcg (pebbly sandstone unit in the Wahweap Formation), Kkl (lower unit of the Kaiparowits Formation), and Kk (typical Kaiparowits Formation). The Hillsdale section is critical for understanding correlations of the upper portion of the Cretaceous section between



Figure 13. Outcrop of the late Eocene Brian Head Formation showing the quarry horizon in 2011.

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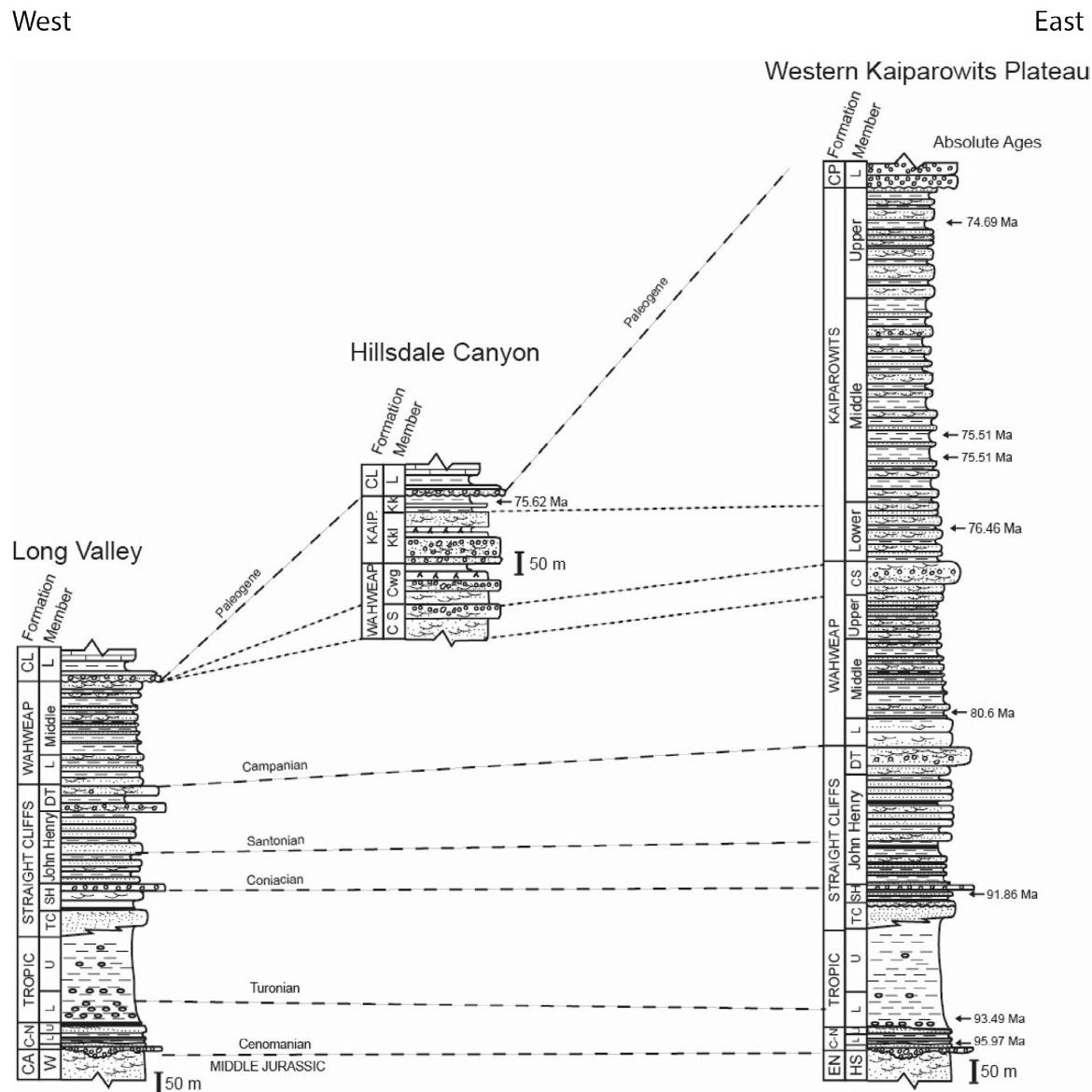


Figure 14. Upper Cretaceous stratigraphic columns for the Paunsaugunt and Kaiparowits plateaus. Abbreviations as follows: CL – Claron; GC – Grand Castle; CA – Carmel; C-N – Cedar Mountain and Naturita; L – Lower; M – Middle; Cwg – pebbly sandstone unit of the Wahweap; Kkl – lower unit of the Kaiparowits; Kk – typical Kaiparowits; DT – Drip Tank; SH – Smoky Hollow; TC – Tibbet Canyon; U – Upper; W – Winsor; CP – Canaan Peak; EN – Entrada; CS – capping sandstone; HS – Henrieville Sandstone. See figure 2 for general location of sections.

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the Markagunt and Kaiparowits Plateaus. The capping sandstone member is overlain there by a conglomerate identical in character to that of the upper Grand Castle Formation, which is in turn overlain by sandstones that increase upsection in black chert lithic content, more typical of the Kaiparowits Formation. The overall coarser grain content of what are mapped as Kaiparowits Formation equivalents is largely due to its proximity to the fold and thrust belt.

The lower portion of the section, including the Cedar Mountain, Naturita, Tropic Shale, and lower Straight Cliffs Formations, are well exposed around Glendale and Orderville, farther south. In general, because of the higher altitude and associated plant cover, the outcrops on the Paunsaugunt are not as extensive as they are on the Kaiparowits, but are generally more fossiliferous with vertebrates than their eastern counterparts. Unfortunately, the Kaiparowits Formation was largely removed from the Paunsaugunt (and Markagunt) areas by pre-Claron aged Laramide uplift (figure 14).

The Cedar Mountain and Naturita Formations are exposed only around the southern and eastern margins of the Paunsaugunt Plateau. Exposures of Naturita Formation along the southwest side of the plateau have produced significant microvertebrate material near the town of Alton (MNA 939/UMNH VP 123).

The Tibbet Canyon Member of the Straight Cliff Formation is quite thin (20 m) along the southern margin of the plateau (Mill Creek section of Eaton, 1993b). The overlying John Henry Member is 190 m thick (figure 5). Along the south side of the plateau a few vertebrate localities have been found (MNA 1201, 1204); but abundant private land has restricted access to the John Henry Member there. Along the eastern margin of the Paunsaugunt Plateau within Bryce Canyon National Park (BCNP), and just east of the park, the John Henry Member is relatively rich in vertebrate fossils. This includes localities in the basal Coniacian part of the member, which range from fish-rich microvertebrate localities (UMNH VP 823-826, 860-866, 1084, 1276) and macrovertebrate localities containing turtles to dinosaurs. Unfortunately, little work has yet been done on this area, the richest known for Coniacian macrovertebrate and microvertebrate fossils in the entire region. Santonian localities are also abundant (UMNH VP 419,

420, 424, 781, 799, 826, 1144) and particular UMNH VP locality 424 (a “blind wash locality”) in the uppermost part of the John Henry Member in BCNP produced a remarkably rich microvertebrate assemblage described in Eaton (2009), Roček and others (2010), Brinkman and others (2013), and Gardner and Demar (2013). The overlying Drip Tank Member is 50 m thick in the Mill Creek section, but is highly variable in thickness around the plateau and is very thin in Tropic Canyon at the northeast corner of the plateau.

The Wahweap Formation on the Paunsaugunt Plateau has been problematic. Gregory (1951) and Doelling and Davis (1989) thought the youngest Cretaceous strata on the plateau belonged to the Kaiparowits Formation. Bowers (1990) and Tilton (1991) considered the uppermost Cretaceous rocks to represent the Wahweap Formation. Eaton (1993) and Eaton and others (1993) favored the Kaiparowits Formation interpretation based on petrology and comparative faunas. Unquestionable Wahweap is found in the Campbell Creek area along the eastern margin of the plateau south of the town of Tropic. Here, the Wahweap Formation mudstones are drab colored and UMNH VP localities 77 and 82 contain abundant shark and ray teeth; both characteristics are common to the Wahweap Formation on the Kaiparowits Plateau. However, in an erosional window through the Claron Formation on top of the plateau (south of Tropic Reservoir), are exposures of colorful variegated mudstone, which contained no shark or ray teeth, but contains the turtles *Compsemys*, *Neurankylus*, as well as kinosternids, taxa that are more common in the Kaiparowits Formation than in the Wahweap (Eaton, 1993b, 1999a). Although initially favored a Kaiparowits Formation equivalency based on the vertebrate faunas, Eaton ultimately accepted the more parsimonious interpretation of Wahweap Formation (Eaton, 1999a) but suggested marked paleo-ecologic controls on the vertebrate fauna that reflect the shift from relatively poorly drained coastal floodplains (preserving organics, having abundant sharks and rays) to the east to better drained more upland settings (variegated mudstone, no sharks and rays) to the west.

Biek and others (2015) described a “lower unit” of the Kaiparowits Formation (Kkl) present on the western side of the Paunsaugunt Plateau that thins eastward

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and completely disappears by the East Fork of the Sevier River. They considered this unit to represent the Kaiparowits Formation, even though it is unlike the typical lithologies of that formation. It is also lithologically unlike the underlying capping sandstone of the Wahweap Formation but is somewhat like the basal Kaiparowits Formation found along Henrieville Creek. The only Kaiparowits Formation with lithologies typical of the strata in its type area is a remnant along the west margin of the Paunsaugunt Plateau in Hillsdale Canyon (Biek and others, 2015; see figure 28). Along the eastern margin of the Paunsaugunt Plateau, the Wahweap Formation has been eroded from the tops of Laramide folds such that in places the Claron Formation rests directly on the Straight Cliffs Formation and the entire Wahweap has been removed (Bowers, 1990; Biek and others, 2015).

The type section of the Limerock Canyon Formation is east of this stop (Kurlich and Anderson, 1997). Work by Kevin Rafferty (2015; a student formerly at Weber State University and now at University of Nevada, Las Vegas) has shown that much of the Limerock Canyon (Miocene) is actually Brian Head Formation. Brian Head localities in this area have produced rodent teeth, ostracods, and charophytes.

39.0 miles – Road cut is in the upper Tertiary fan alluvium (Taf) and includes an exposure of the 5.0 Ma Rock Canyon lava flow (Biek and others, 2015).

45.2 miles – Intersection of US 89 and SR 12, turn right onto SR 12. White outcrops at this intersection have been blind washed and produced latest Miocene rodents (William Korth, Rochester Institute of Paleontology, written communication to Eaton, 2016), as well as unaltered gastropods and bivalves (UMNH VP locality VP 1999, IP locality 89).

47.8 miles – Sevier fault.

48.0 miles – Red Canyon; note conglomerate on the left side of the road in the Claron Formation. Conglomerate becomes more common to the northwest.

53.5 miles – Town of Tropic, Utah, and the type sec-

tion for the Cretaceous marine Tropic Shale.

End of Day 1.

DAY 2: CRETACEOUS STRATIGRAPHY AND PALEONTOLOGY OF THE PAUNSAUGUNT AND KAIPAROWITS PLATEAUS

0.0 miles – Tropic, Utah, at the intersection of 200 North and SR 12. Proceed west on SR 12.

3.5 miles – Paunsaugunt fault. Gray beds of the John Henry Member of the Straight Cliffs Formation faulted against the lower red member of the Claron Formation. This normal fault has the same general orientation as the Sevier fault on the west side of the Paunsaugunt Plateau.

7.4 miles – Intersection with SR 63 to Bryce Canyon Nation Park. On the eastern flank of the park there are extensive exposures of the John Henry Member of the Straight Cliffs Formation and the Wahweap Formation. Eaton conducted a five year (2006-2010) inventory of fossil resources within the park. Both the John Henry Member and the Wahweap Formation are more fossiliferous there than on the Kaiparowits Plateau and hundreds of localities were identified. Only a few localities were intensively worked because of the lack of access. Bulk mudstone samples taken to process for microvertebrates had to be back-packed out of the park, often requiring 3 hours of hiking per sack of matrix in the middle of summer. One of the most significant localities is UMNH VP locality 424 (figure 15) which is almost at the top of the John Henry Member and is the richest microvertebrate site yet known from that member (see appendix for a complete listing of taxa).

10.3 miles – Turnoff to Tropic Reservoir. Make a left turn and proceed south.

17.3 miles – Tropic Reservoir. Continue south. From about this point south, outcrops in the lower portions of the valley are of the middle Campanian Wahweap Formation overlain unconformably by the Claron Formation.

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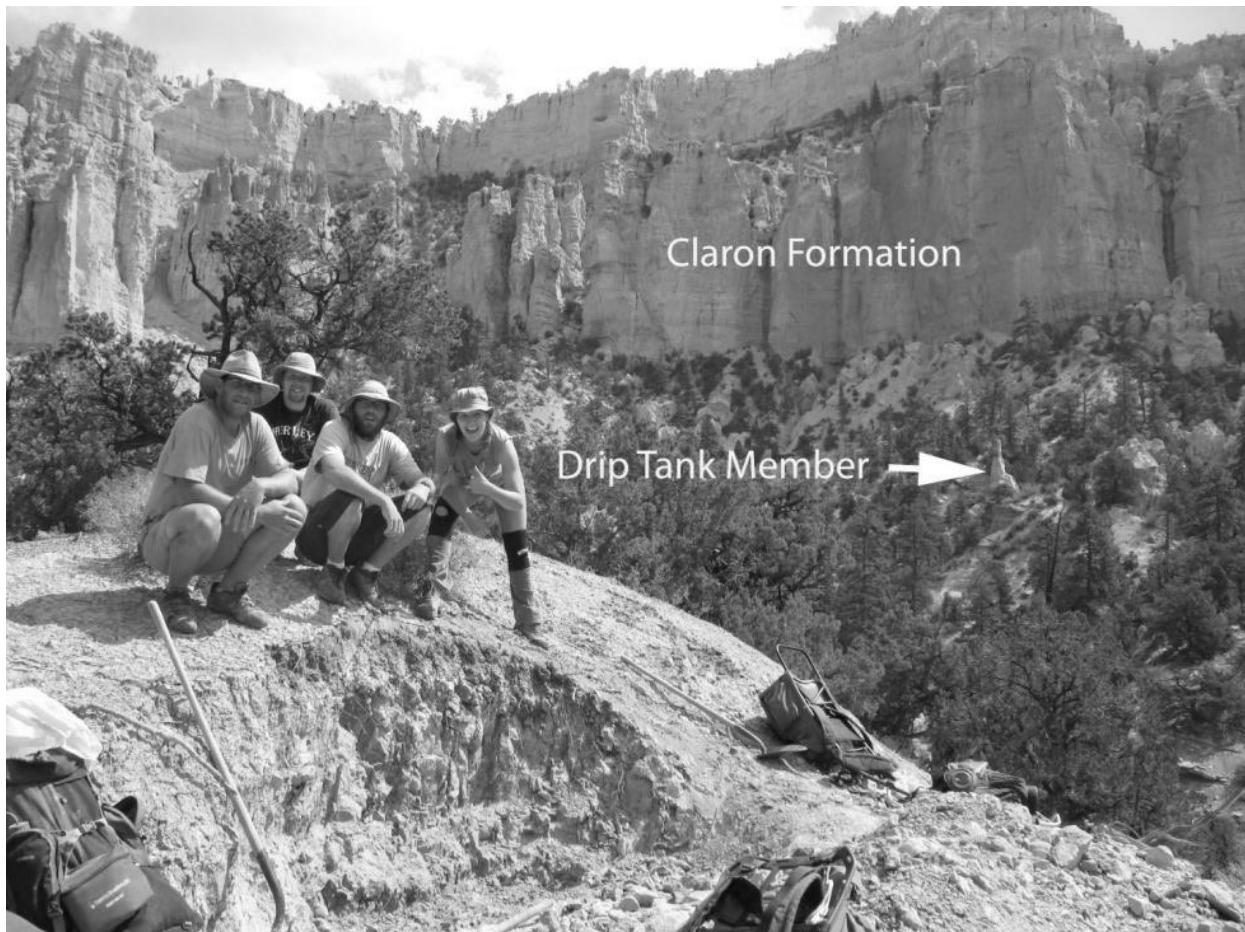


Figure 15. UMNH VP Locality 424 (Santonian), near the top of the John Henry Member of the Straight Cliffs Formation. Note the Drip Tank Member just above the locality. Here the Claron Formation rests unconformably on the Drip Tank Member due to erosion across the Laramide aged Bryce Canyon anticline.

21.6 miles – STOP 7. WAHWEAP FORMATION ON THE PAUNSAUGUNT PLATEAU – MILL CREEK AREA (UMNH VP locality 83/MNA locality 1073): The Wahweap Formation on the Paunsaugunt Plateau is exposed in a window eroded through the Claron Formation by the East Fork of the Sevier River and its tributaries. This stop, UMNH VP locality 83/MNA locality 1073, in the Mill Creek area, is one of the most easily accessed of all the highly fossiliferous localities (figure 16). The obvious interpretation of these strata, based on their stratigraphic position, would be the Wahweap Formation, but aspects of the lithology and fossil content were questioned (Eaton, 1993b; Eaton and others,

1993). The Wahweap Formation on the Kaiparowits Plateau (type area) consists of rather drab organic-rich floodplain mudstones and siltstones and laterally aggrading channel sandstone. Eaton and others (1993) noted that the sandstone high in the Wahweap section on the Paunsaugunt Plateau were petrologically more similar to the Kaiparowits Formation than to sandstone of the Wahweap Formation. Biek and others (2015) have now mapped these sandstone beds as the lower Kaiparowits Formation (Kkl). The Wahweap mudstone exposed here also differ markedly from those of the type area as they are variegated and very fossiliferous.

Sampling the Wahweap Formation on the Kaiparowits Plateau for microvertebrate fossils commonly

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Figure 16. Typical variegated fossiliferous mudstone of the Wahweap Formation along Mill Creek at UMNH VP locality 83/MNA locality 1073.

produces shark and ray teeth as well as crab claws, with other taxa much less common. On the Paunsaugunt Plateau recovered fossils (see appendix) include taxa that are common in the Kaiparowits Formation but rare or unknown from the Wahweap Formation of the Kaiparowits Plateau. The Paunsaugunt Wahweap strata also lack ray and shark teeth or crab claws indicating a fundamental environmental shift between the two regions, most likely a more upland, better drained environment with less coastal influence. The mammalian fauna (Eaton, 1993b) also initially did not compare well to that of the Wahweap Formation on the Kaiparowits Plateau. For these reasons Eaton (1993b) and Eaton and others (1993) kept open the possibility that these strata might represent the Kaiparowits Formation or possibly another unit. However, subsequent study of the fauna (Eaton, 2013), aided by systematic revisions by other workers, showed a reasonably good correlation with the fauna of the Wahweap Formation to the east. The difference in the overall vertebrate fauna seems to reflect a shift from relatively poorly drained coastal floodplains to better drained more upland floodplains.

Return to Tropic and reset trip meter.

0.0 miles – Intersection of 200 N with SR 12. Proceed east.

1.6 miles – Road cut exposes upper marine portion of the Naturita Formation and lowermost beds of the Tropic Shale.

4.7 miles – Entering Cannonville.

4.8 miles – Turn right (south) onto the Cottonwood Canyon Road to Kodachrome Basin State Park.

4.9 miles – **STOP 8. OVERVIEW OF NATURITA FORMATION, PAUNSAUGUNT-KAIPAROWITS TRANSITION:** To the west of the Cannonville town park and Grand Staircase-Escalante National Monument visitor center parking lots, the red- and white-banded Cannonville Member of the Entrada is in view and overlain by the Naturita Formation cutting out much of

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the intervening bleached looking Henrieville Sandstone (figure 17). The Henrieville Sandstone as described by Thompson and Stokes (1970) is somewhat controversial as a map unit and has been synonymized with the upper portion of the Entrada Sandstone by some workers (Bowers, 1983; Biek and others, 2015). Resolution of this issue awaits more detailed lithologic study of all the potentially correlative units. For this guide, we retain these beds in the Henrieville Sandstone. The Cedar Mountain Formation is locally absent, being discontinuous over much of the Kaiparowits Plateau. Thin, gravelly facies at the bottom of the Naturita in this region are probably reworked Cedar Mountain sediments. Here, on Bulldog Bench, the nonmarine lower unit of the Naturita Formation is unusually fossiliferous with vertebrates, including mesovertebrate remains such as turtles and crocodylians. Although many localities have been discovered, only one has been extensively screen washed (figure 18) – MNA 1067/UMNH VP locality 27. This remarkable locality has produced mammalian jaws, including early marsupials, but also large lungfish plates, and material of frogs and lizards (see appendix). The mesovertebrate fossil content of the Naturita appears to be highest trending between Bulldog Bench and the

southwestern margin of the Kaiparowits Plateau, where turtle and crocodylian remains are similarly abundant. The Naturita in the Kaiparowits region contains abundant coal and carbonaceous beds. Macrovertebrate skeletal remains are virtually unknown although dinosaur trackways and teeth recovered from microsites indicate the region was inhabited by larger animals.

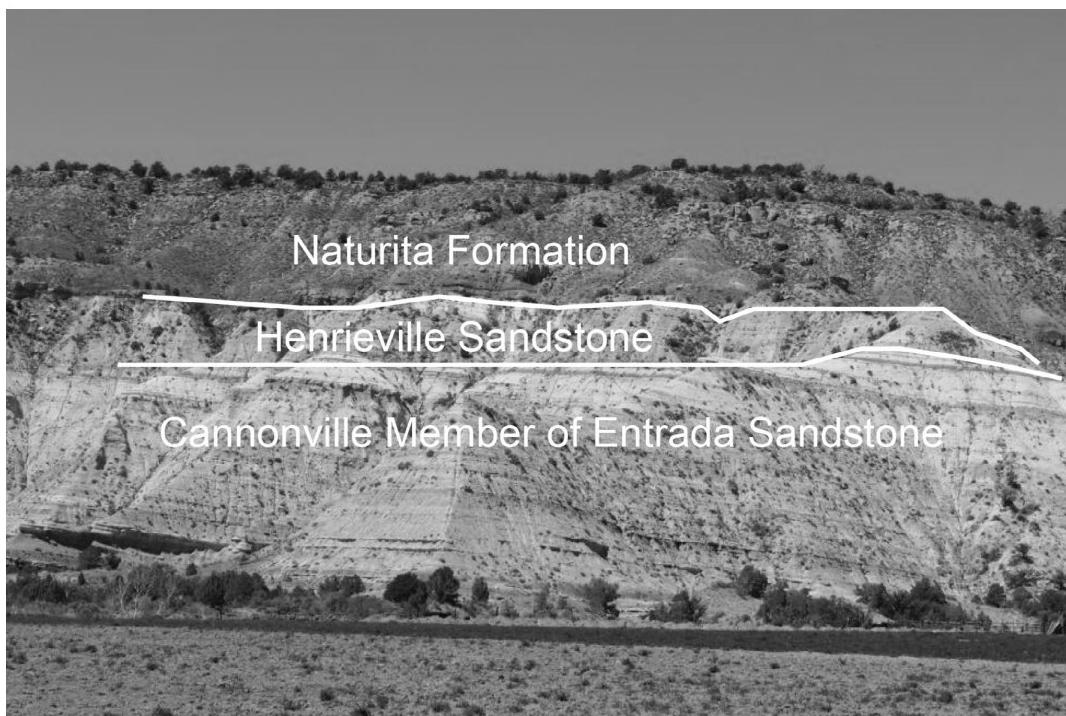
Return to SR 12.

5.0 miles – Turn right (east) onto SR 12.

9.7 miles – Outcrops of the Middle Jurassic Henrieville Sandstone (overlying Entrada Sandstone) overlain by the lower and upper members of the Naturita Formation visible to the west of SR 12 (figure 19).

11.2 miles – **STOP 9. OVERVIEW OF KAIPAROWITS PLATEAU STRATIGRAPHY, THE NATURITA FORMATION, AND THE TROPIC SHALE:** From SR 12, hike approximately 0.16 km due south to the Naturita-Tropic contact. The basic Cretaceous stratigraphy of the Kaiparowits Plateau (figure 20) was established by Gregory and Moore (1931), Lawrence (1965), Peter-

Figure 17. Henrieville Sandstone (Jurassic)–Naturita (Cretaceous) Formation contact on Bulldog Bench. The lower nonmarine Naturita Formation is much thicker here than anywhere else in the Kaiparowits-Paunsaugunt Plateaus region.



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Figure 18. MNA 1067/UMNH VP locality 27 quarry in the Naturita (Dakota) Formation on Bulldog Bench. This appears to be an overbank deposit immediately adjacent to a meandering river levee. Large material is found along the levee and fines rapidly away from the levee. There are clearly several flood events separated by organic mats.

son (1969), and Eaton (1991). The Upper Cretaceous section is approximately 2600 m thick and fairly similar throughout the region, but there are some marked facies changes in formations, mostly trending east-west. As a rule, exposures are much better for all of the units in this region than they are in either the Paunsaugunt or Markagunt Plateaus. The oldest unit mapped is the Cedar Mountain Formation, which in the Kaiparowits region is mostly limited to the pebbly conglomerate facies. The smectitic gray mudstone facies is absent. In the Kaiparowits Basin, the overlying Naturita Formation is relatively thin, averaging only 30 to 35 m in thickness. As it overlies the basal Cretaceous unconformity and in turn is overlain by the marine Tropic Shale, it represents a variety of terrestrial and nearshore marine environments, in a generally retrogradational sequence. With the exception of shark and fish remains, vertebrate fossils are largely confined to the lower member, occurring in floodplain, channel, and crevasse splay facies. Large mesovertebrate and macrovertebrate remains are generally uncommon and usually occur as isolated elements, but 0.3-m-diameter turtle shells can be locally abundant in lacustrine and channel facies, particularly

in the southwestern portion of the Kaiparowits Basin. The Bulldog Bench area near Tropic (Stop 8) is one of the only places where larger vertebrates besides turtles have been found in any quantity. Dinosaur trackways also occur sparingly in the middle unit (Titus and others, 2013).

The overlying Tropic Shale is as much as 300 m thick (Doelling and Davis, 1989), entirely marine in origin, and spans late Cenomanian to middle Turonian time. The formation is dominantly gray-weathering mudstone, but calcisiltites and calcarenites also occur throughout the formation. The lower half of the Tropic is more carbonate rich, whereas the upper half is more siliciclastic. Fossils, mostly invertebrates are common throughout, but vertebrate remains are only locally common. Non-fish vertebrates are uncommon to rare, but long-term collecting has revealed a highly diverse assemblage that will be discussed in more detail below.

The overlying Straight Cliffs Formation is a highly heterogeneous unit that probably exhibits the most lateral variation of any formation in the Kaiparowits Basin. Spanning much of the later Turonian, as well as the entire Coniacian and Santonian, it also represents the longest time span (~ 10 Ma) of any Cretaceous formation in the region except for the related Iron Springs Formation. In general, marine and marginal-marine facies dominate the eastern outcrops, with shoreface, beach complex, estuarine, and deltaic beds interleaved with coastal mire and distributary fluvial units (Allen and Johnson, 2010), whereas western outcrops are composed mostly of meandering fluvial and floodplain deposits. The unit was deposited during the end of the Greenhorn and throughout the entire Niobrara cyclothems (middle Turonian to late Santonian age). In the Kaiparowits Basin the Straight Cliffs locally produces abundant microvertebrate remains. However, macro and mesovertebrate sites are actually somewhat rare. The highest densities of such sites occur in the southwest portion of the Kaiparowits Plateau where alluvial-plain facies dominate. There multiple sites yielding dinosaur material, including a multi-individual ornithopod bonebed have been found, but not in the same quantities as observed on the Paunsaugunt Plateau. Dinosaur trackways are locally known, particularly in coal seems, but bone is quite rare in the eastern half of the

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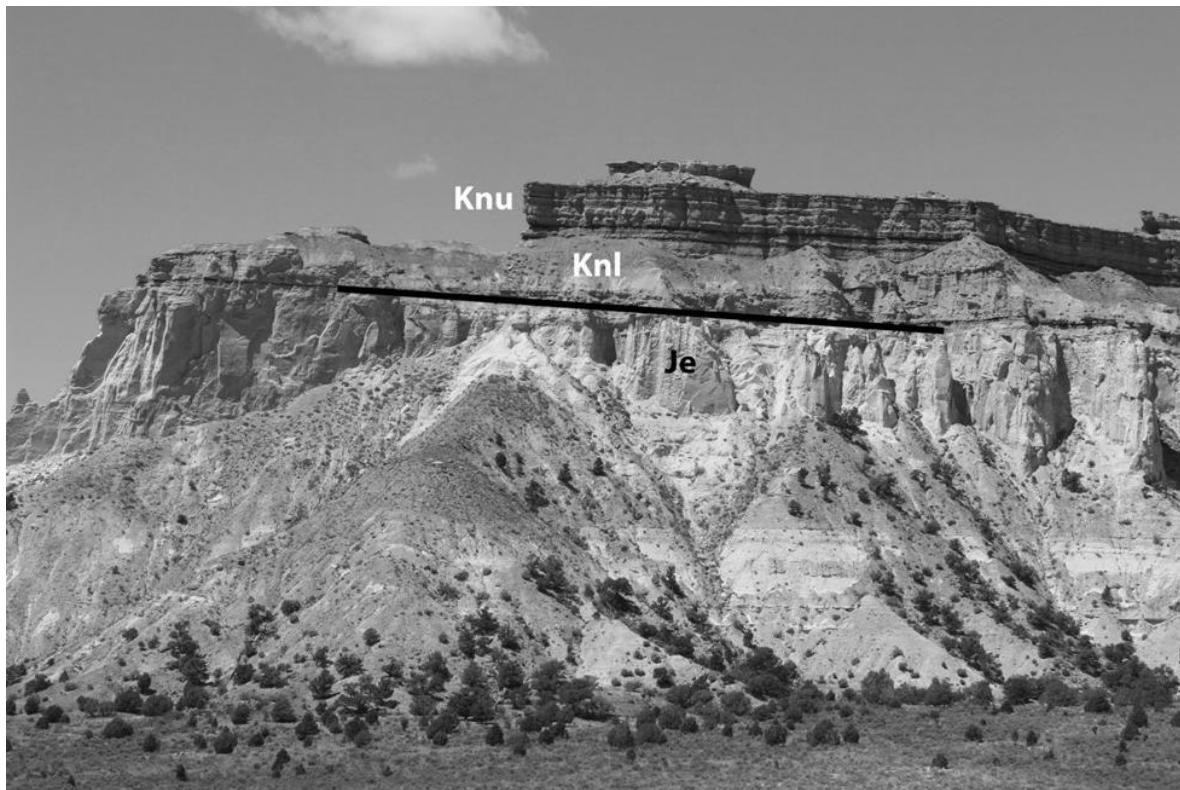


Figure 19. Henrieville Sandstone (Je) in contact with the Naturita (KnI, Knu) Formation. There is very little lower nonmarine Naturita even though this outcrop is only about 16 km from Bulldog Bench.

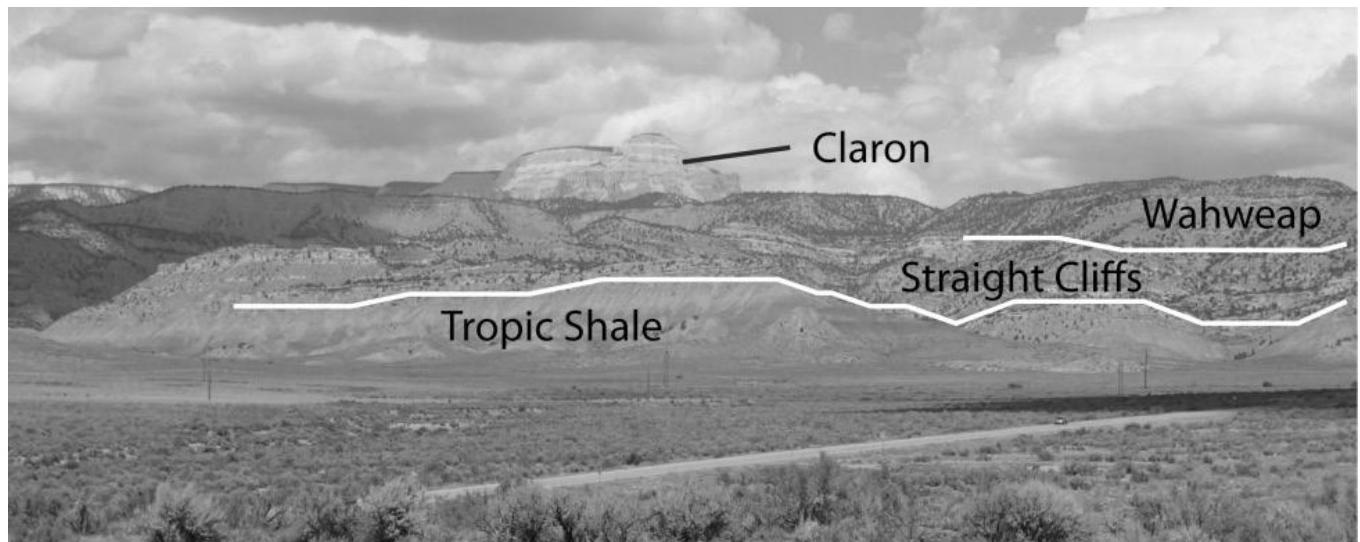


Figure 20. Kaiparowits Plateau stratigraphy visible from Stop 9. The Kaiparowits Formation is not visible, but widely exposed behind the ridge formed in the Wahweap Formation. The highest outcrops of white-colored Eocene age Claron Formation are at Powell Point, at the very south end of the Table Cliffs Plateau. See figure 23 for wide view.

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plateau, leading to the conclusion that either the depositional rates or soil conditions were unfavorable to preservation of large bone.

The seaway withdrew at the end of the Niobrara cycle never to inundate southern Utah again. As a result, the overlying Wahweap and Kaiparowits Formations are entirely terrestrial in origin and fairly homogeneous, although not without marine influence on their deposition and occasional brackish water incursions (e.g., Roberts and others, 2008).

The marine portion of the upper Naturita at this stop consists of alternating (cyclic) mudstone and sandstone deposited in a shallow, near-shore muddy shelf setting during the early Greenhorn cyclothem event. Mollusk assemblages alternate between oyster epiboles and more diverse assemblages reflecting fluctuating sea levels. A thin coal bed just below the top of the formation marks a lowstand associated with the top of the *Metoicoceras mosbyense* biozone. The biostratigraphically useful inocermid bivalve *Inoceramus fragilis* occurs near the base of the member, whereas ammonites of the *Dunveganoceras problematicum* and *Metoicoceras mosbyense* biozones occur in the middle and top of the unit, respectively. Collectively, the marine invertebrate record indicates the upper member is entirely late Cenomanian, spanning much of that substage. Vertebrates are not common, and consist mostly of isolated elements of brackish and marine chondrichthyans and osteichthyans.

The overlying Tropic Shale (figure 21) was deposited in an open water, offshore muddy shelf setting. At peak transgression, the shoreline was over 115 km to the west. The Tropic Shale is mostly gray mudstone and contains abundant invertebrate and vertebrate fossil fauna. Ammonites in the formation indicate it spans the *Vascoceras diartianum* through *Prionocyclus hyatti* ammonite biozones (middle late Cenomanian to middle middle Turonian). The nearshore position of the Tropic Shale depocenter in a regime of relatively high accommodation space make the Cenomanian-Turonian stratigraphic record in the region especially thick and complete (Elder and others, 1994). In particular, the events surrounding ocean anoxic event II (OAE II) and the associated extinction are recorded in great detail (Elder, 1991). Most of the large vertebrate fossils are

found in the early Turonian, although rare specimens are known from the underlying Cenomanian (Gillette and others, 1999). An overview of the vertebrate fauna was given by Albright and others (2013) and the described fauna is summarized in the appendix. Chondrichthyan and osteichthyan remains including fully articulated specimens occur commonly in the Tropic, but no detailed studies have ever been published. Over the last 16 years a diverse and significant marine reptile fauna has been recovered from the unit. Plesiosaur remains are most common, but turtles, early mosasaurs, and rare dinosaur remains have also been found. Five taxa of plesiosaurs (one pliosaurid and four polycotylids) are now documented from the formation (figure 22), making the assemblage one of the most diverse known from any Greenhorn age deposits. Three significant trends/events in vertebrate evolution appear to be recorded in the Tropic: (1) the extinction of the archaic pliosaurid plesiosaurs, (2) the diversification of the polycotylid plesiosaurs, and (3) the rise of true mosasaurs in North America.

11.6 miles – View north towards Jimmy Canyon is of the open marine Tropic Shale and the shoreface facies of the Tibbet Canyon Member forming the cliff, which holds up the benches. Resting on the benches is the paludal Smoky Hollow Member (Turonian). On the bench directly to the north (figure 23) is the richest Smoky Hollow Member micro-site known, MNA 995/UMNH VP locality 129. This very productive site is difficult to recover large quantities of matrix from (figure 24). In 1991, a small helicopter made several trips to move 86 moderately sized sacks of matrix from the bench to the valley floor. This locality has provided much of the basis for the faunal list presented in the appendix.

13.0 miles – Turnoff to Henderson Canyon (figure 25). The lower John Henry Member contains coals (figure 26), is very organic rich, and produces a brackish-water fauna of both vertebrates and invertebrates (e.g., MNA 706-2/UMNH VP locality 98). The upper part of the John Henry Member in Henderson Canyon is less organic rich (figure 27) and includes UMNH VP locality 99 (Santonian), a very productive microvertebrate locality from which much of the vertebrate faunal

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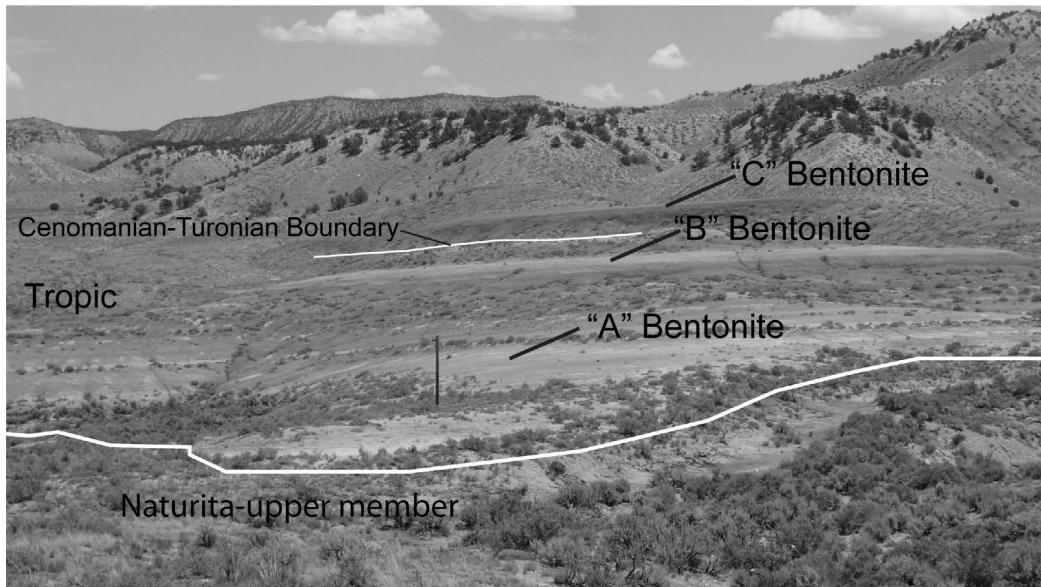


Figure 21. Overview of the Tropic Shale at Stop 9. Lettered bentonites are key marker beds (of Elder, 1991) that can be traced throughout the southern Western Interior, including the Cenomanian-Turonian Boundary Global Stratotype Section and Point near Pueblo, Colorado.

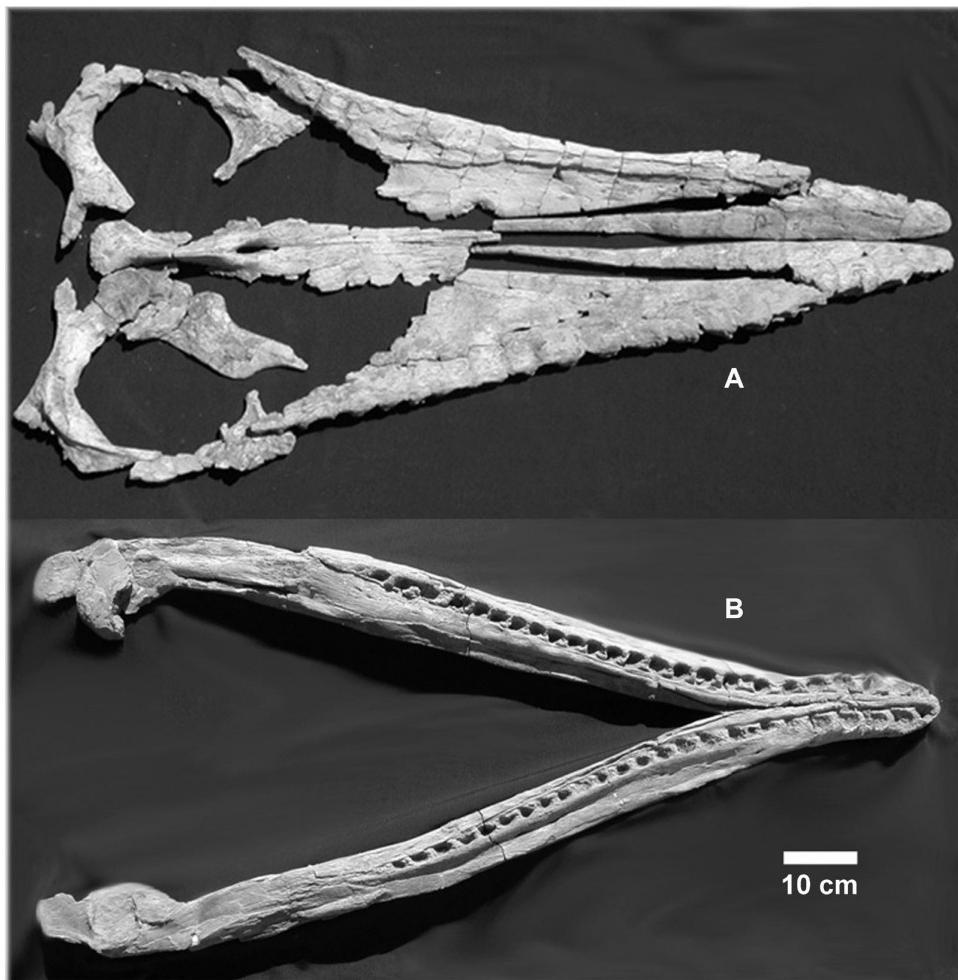


Figure 22. MNA V9433, (A) Dorsal view of nearly complete cranium, and (B) dorsal view of complete mandible of the pliosaurid plesiosaur *Brachauchenius lucasi*. From Albright and others (2013).

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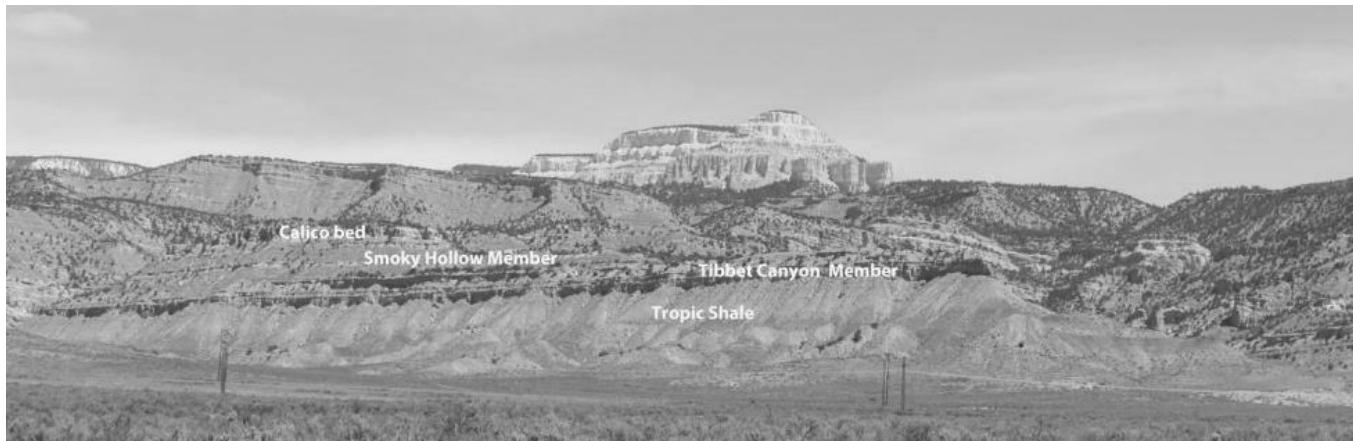


Figure 23. Looking northeast at bench with MNA 995/UMNH VP locality 129 in the Smoky Hollow Member of the Straight Cliffs Formation.



Figure 24. The late Jared Morrow at MNA 995/UMNH VP locality 129 quarry, Smoky Hollow Member of the Straight Cliffs Formation, Turonian.

list in the appendix is derived.

14.2 miles – STOP 10. SMOKY HOLLOW AND JOHN HENRY MEMBERS OF THE STRAIGHT CLIFFS FORMATION: The Tibbet Canyon Member is overlain by the early late Turonian Smoky Hollow Member, which has coal and lignite low in the member (figure 28). It also contains brackish-water faunas. The upper part of the member consists of beds of fluvial

deposition. The Smoky Hollow Member is capped by fluvial sandstone and conglomerate termed the Calico bed by Peterson (1969). The John Henry Member is upper Coniacian-Santonian and rests disconformably upon the Calico bed (figure 29). As with the underlying Smoky Hollow Member, the lower part of the John Henry Member is very carbonaceous and contains brackish-water faunas (listed in appendix). The upper part of the formation here is largely nonmarine; how-

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Figure 25. View of the looking north up Henderson Canyon from the SR 12 turnoff of the Tropic Shale and overlying members of the Straight Cliffs Formation.



Figure 26. Typical coal and sandstone interbeds in the lower John Henry Member in Henderson Canyon.

ever, thin sandstone tongues containing marine taxa are present in the unit. Along the eastern margin of the plateau (type section for the Straight Cliffs Formation) the John Henry Member is mostly nearshore to marine.

14.8 miles –**STOP 11. UPPER JOHN HENRY AND DRIP TANK MEMBERS, STRAIGHT CLIFFS-WAHWEAP FORMATIONS:** On the north side of the canyon, the prominent cliff-forming Drip Tank Member of the Straight Cliffs Formation (Santonian) is unconformably overlain by the less resistant ledge-forming sandstone and mudstone of the lower member of the Wahweap Formation (figure 30). The Drip Tank Member in the Kaiparowits Basin is locally fossiliferous with vertebrate material, including dinosaur bone, but owing to the high-energy nature of its depositional system, most of the material is fragmentary and non-diagnostic.

The overlying alternating sandstones and mudstones of the Wahweap Formation are well exposed in this area (figure 30), but the formation generally forms steep slopes making it difficult to prospect for fossils. In the Kaiparowits region, most of the identifiable macrovertebrate remains have been collected from along the Smoky Mountain road and the southern margin of the plateau. The unit is also more paralic in character here than in the Paunsaugunt region, commonly containing carbonaceous beds indicative of paludal environments.

The majority of the macrofauna of the Wahweap Formation is now well constrained as older than the oldest described assemblages of the Judith River and Foremost Formations (Albright and Titus, 2016), and it includes the oldest named North American representatives of the Tyrannosauridae (*Lythronax*), Lambeosaurinae (*Adelopholus*), Centrosaurinae (*Diabloceratops*), and Pachycephalosauridae dinosaur clades. At least two different species of large alligato-

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Figure 27. Upper part of the John Henry Member in Henderson Canyon. Note channel complex at the top of the member. UMNH VP locality 99 is in the underlying fine-grained part of the section.

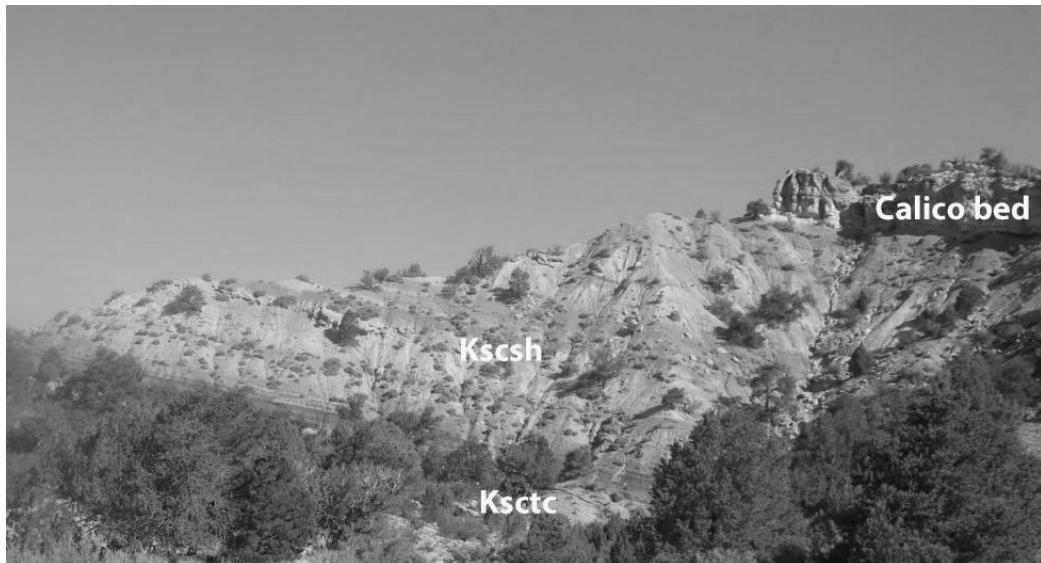


Figure 28. The Smoky Hollow Member (Kscsh) overlies the nearshore deposits of the Tibbet Canyon Member (Ksctc); note the carbonaceous horizons low in the Smoky Hollow Member. The Smoky Hollow is capped by the sandstones and conglomerates of the Calico bed.

roids and a pholidosaur-like crocodylian have also been recovered, but await description. Cranial material of a nodosaurid ankylosaur was also recovered recently but is also awaiting description. Based on the hadrosaurs (Gates and others, 2014) and ceratopsids, the early middle Campanian Wahweap dinosaur assemblage has

some similarity to the slightly younger Foremost and Oldman assemblages found in Alberta, Canada.

16.4 miles – **STOP 12. CAPPING SANDSTONE MEMBER AND LOWER KAIPAROWITS FORMATION:** In this vertical cliff face exposed along Henriev-

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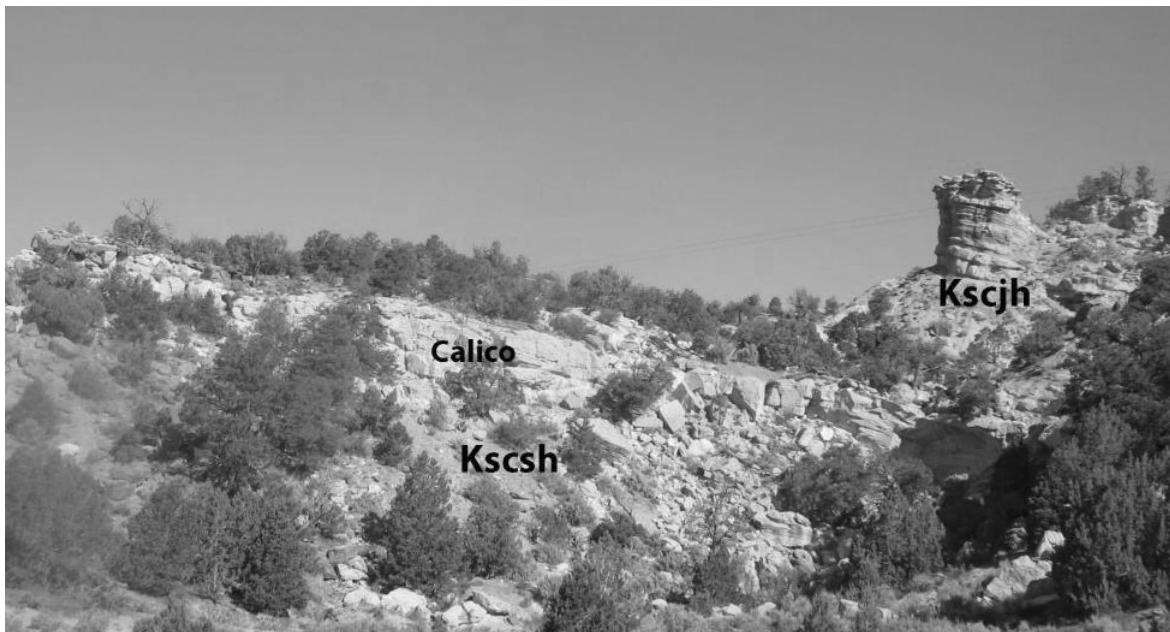


Figure 29. The Calico bed of the Smoky Hollow Member (Kscsh) is overlain disconformably by the John Henry Member (Kscjh). The lower John Henry is locally very carbonaceous and produces a brackish-water fauna.



Figure 30. Contact between the upper part of the John Henry Member and the Drip Tank Member along Henrievile Creek. The Drip Tank Member is a quartz arenite to pebbly conglomerate as opposed to the non-conglomeratic feldspathic sandstones of the upper John Henry Member. Kw = Wahweap Formation.

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ille Creek (figure 31) is the contact between the capping sandstone member of the Wahweap (Kwcs) and the base of the Kaiparowits Formation (Kk). Lawton and others (2014) noted a 26-m interval at the base of the Kaiparowits Formation, which they considered transitional between the sandstone lithology of the Wahweap Formation and the more feldspar-rich lithology of Kaiparowits Formation. Several fossil localities were found in the lowest part of the Kaiparowits, which produced ostracods and miscellaneous vertebrate materials including ray teeth (Lawton and others, 2014).

18.2 miles – Turn on small dirt road and proceed about 100 m to the north and park. **STOP 13. KAIPAROWITS FORMATION OVERVIEW:** From this view you can see most of the gray-colored middle and upper members of the Kaiparowits Formation below the prominent cliff-forming outcrops of the Claron Formation. The intervening slope between the Kaiparowits and Claron Formations is formed in the Canaan Peak and Pine Hollow Formations and other coarse clastic units referred to the Grand Castle Formation, but which cannot belong to that formation because they post-dates the Kaiparowits Formation. These formations are not visible from this vantage point because they are covered with slumps and vegetation. Outcrops to the east (figure 32) form the type section of the Kaiparowits Formation, which here is approximately 860 m thick. The immediate foreground is in the middle member, about 200 m above the base of the formation (Eaton, 1991, figure 15). Although the section appears dominantly composed of mudstone, it is close to an even mix of sandstone and mudstone. However, the sandstone beds are generally friable and weather into rounded shapes that resemble more mud-rich outcrops. Dated ash-fall tuffs in the Kaiparowits Formation have yielded an age range of 76.6 to 74.5 Ma, which spans most of the lower half of the late Campanian (Roberts and others, 2013); however, given its thickness the Kaiparowits was deposited at a remarkably fast rate (Roberts and others, 2013). What is possibly even more remarkable is that the entire formation was removed from portions of the Paunsaugunt and Markagunt Plateaus area in the early to middle Paleocene during the Laramide uplift. The Kaiparowits is by far the richest macrovertebrate-producing unit in

the entire region.

18.7 miles – STOP 14. MIDDLE KAIPAROWITS SEDIMENTOLOGY AND TAPHONOMY: Park on south side of highway, east of culvert. Hike down into creek and north into the culvert. Emerge on other side in small canyon carved into middle member of the Kaiparowits Formation. Many features of Kaiparowits depositional systems can be observed in the canyon walls in good detail. Exposed are overbank, fine-grained sequences that have carbonate pedogenic features, which are incised, scoured, and overlain by fluvial channel sandstones bearing large carbonized logs and fossil-rich lags. Whereas the overall vertebrate diversity of the Kaiparowits has mostly been assessed from mudstone-rich pond and floodplain lake facies, many of the articulated macrovertebrate specimens, some displaying soft tissue impressions, are found at the bases of these channel systems, above the scours. Many associated macrovertebrate specimens actually bear mudstone or pedogenic carbonate in their interstices, indicating that they were reworked into the channels from finer grained facies.

The preservation of individual Kaiparowits vertebrate specimens is sometimes spectacular (figure 33). Complete or partial articulation and preservation of softer elements such as epidermis and the keratinous portions of beaks and claws is not rare, particularly in fluvial channel facies. The turtles *Adocus* (Knell and others, 2011) and *Basilemys* have both been found preserved with clutches of eggs (figure 34). Unusual paleobiological information has also been gained from rare specimens showing predatory or behavioral traits (e.g., Boyd and others, 2013). The distribution of fossils is irregular throughout the formation although the lower and middle portions of the middle member are by far the most fossiliferous. Fossil content largely is inversely proportional to the maturation of calcic paleosol features that are pervasive in overbank sequences. Reworking of vertebrate materials of all size classes, including associated dinosaurs, out of finer grained overbank facies into fluvial channel bottom lags is a very common preservational mode. Soft tissue preservation is most often observed as primary burials in fluvial channels, although rarely hadrosaurs have been observed with soft

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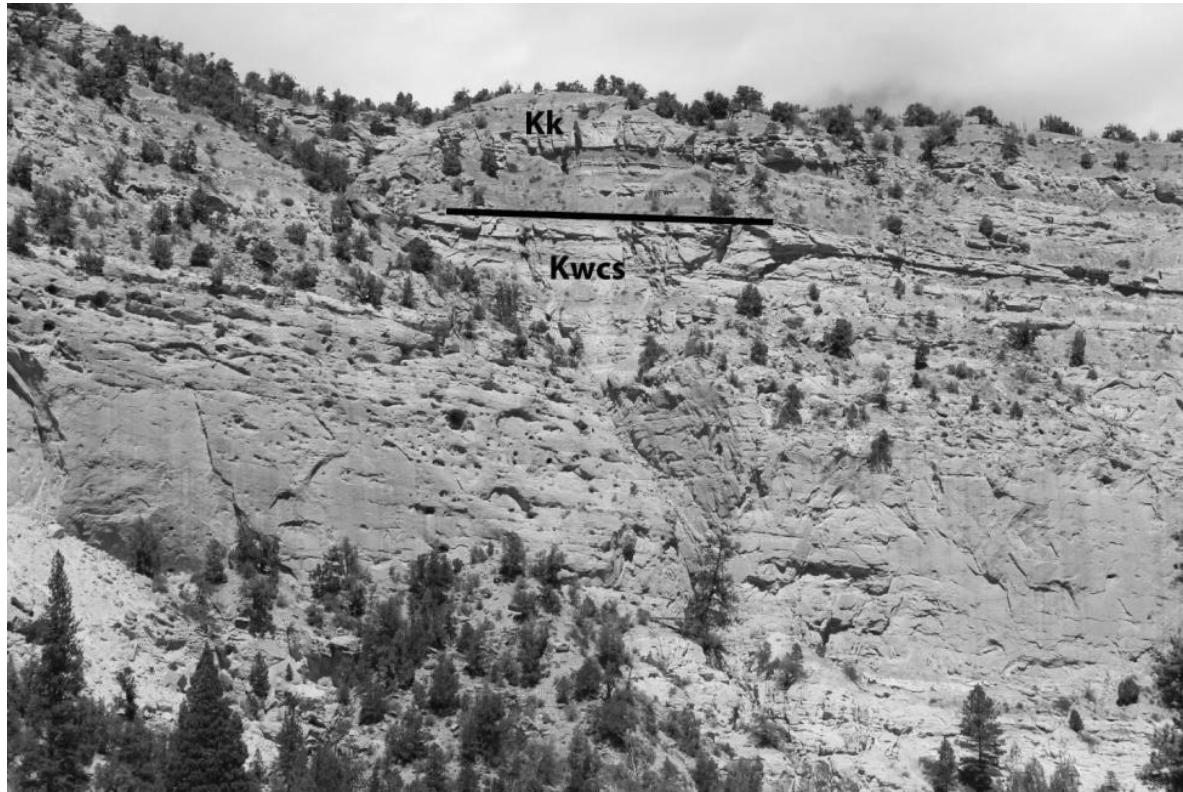


Figure 31. Contact between the capping sandstone member of the Wahweap Formation (Kwcs) and the Kaiparowits Formation (Kk) along Henrieville Creek.



Figure 32. Outcrops of the lower Kaiparowits Formation (above 200 m) in the Blues, the type section of the Kaiparowits.

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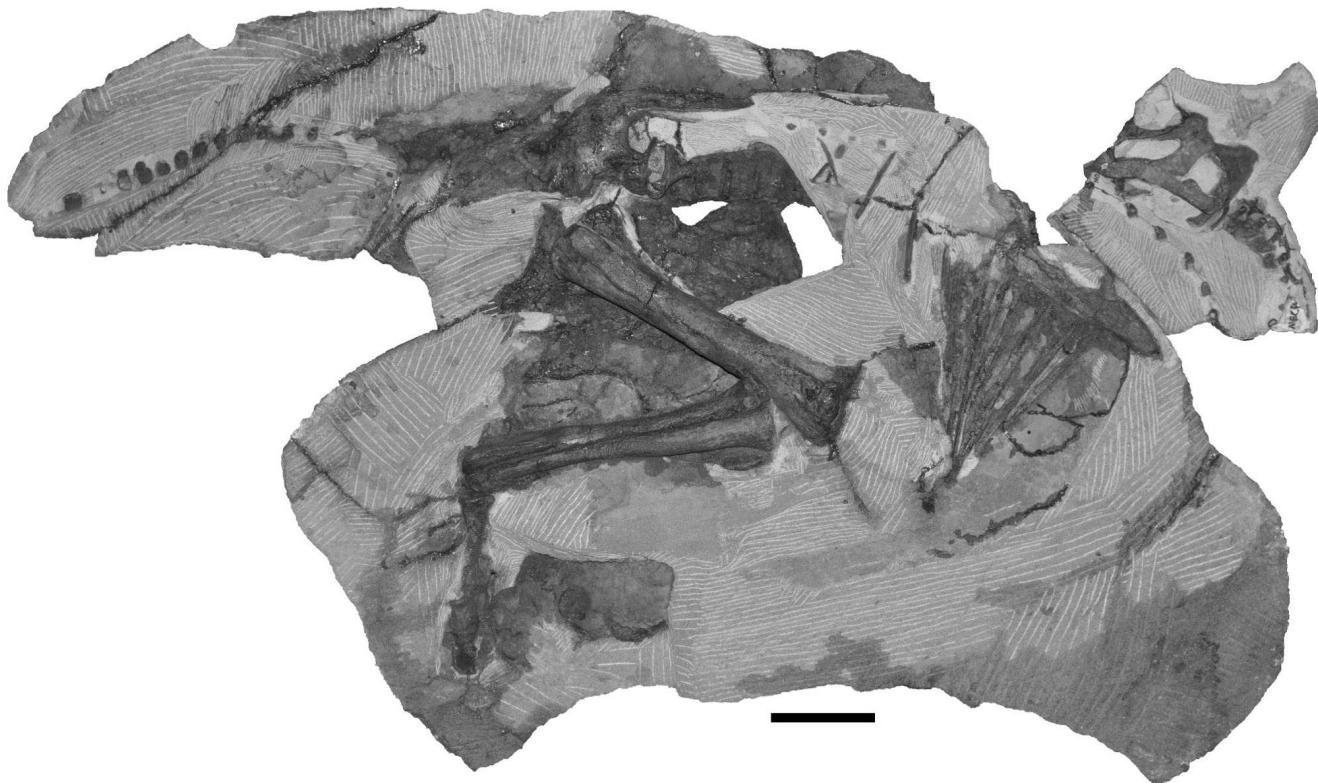


Figure 33. RAM 14000, an exceptionally well preserved juvenile specimen of the dinosaur *Parasaurolophus* sp. Individual is fully articulated and exhibits soft tissue preservation. The black scale bar is 10 cm. Photograph by Raymond Alf (Museum of Paleontology).

tissue preserved in calcite concretionary overgrowths in floodplain lake facies. Strong correlation between suites of invertebrate fossils and depositional facies (Tapanila and Roberts, 2013) shows promise for vertebrate assemblages. Indeed, anecdotal observations seem to support gross separation of fluvial and overbank assemblages of both microvertebrates and macrovertebrates. A 0.8-km-long hike to the northeast towards the very first *Utahceratops* quarry will afford a look at a typical associated hadrosaur site that includes skin impressions.

20.7 miles – STOP 15. KAIPAROWITS FORMATION DIVERSITY- THE BLUES OVERLOOK: The Kaiparowits Formation flora (Miller and others, 2013), invertebrate fauna (Tapanila and Roberts, 2013), and vertebrate fauna are exceptionally diverse (see appendix). Although these are the most accessible outcrops of the formation, most of the type localities for

new dinosaurs and other macro and mesovertebrate taxa are actually out of view and to the south of Canaan Peak. Two exceptions to this are the type specimens for the oviraptor *Hagryphus giganteus* and the troodontid *Talos sampsoni*, both of which were collected in the lower elevation hills due west of the overlook (figure 35).

The most common large dinosaur remains are lambeosaurine and saurolophine dinosaurs. Ceratopsids are found in lesser numbers, but are still clearly a significant part of the ecosystem, displaying exceptionally high diversity. Most other dinosaur taxa are uncommon to rare, some being represented by a single specimen (e.g., *Hagryphus*). The only larger elements of the fauna besides dinosaurs are two taxa of crocodylians, a pholidosaur very similar to *Denazinasuchus* and *Deinosuchus*. Ongoing reconnaissance efforts in the Kaiparowits Formation continue to add to its diverse vertebrate fauna and have rapidly enhanced the

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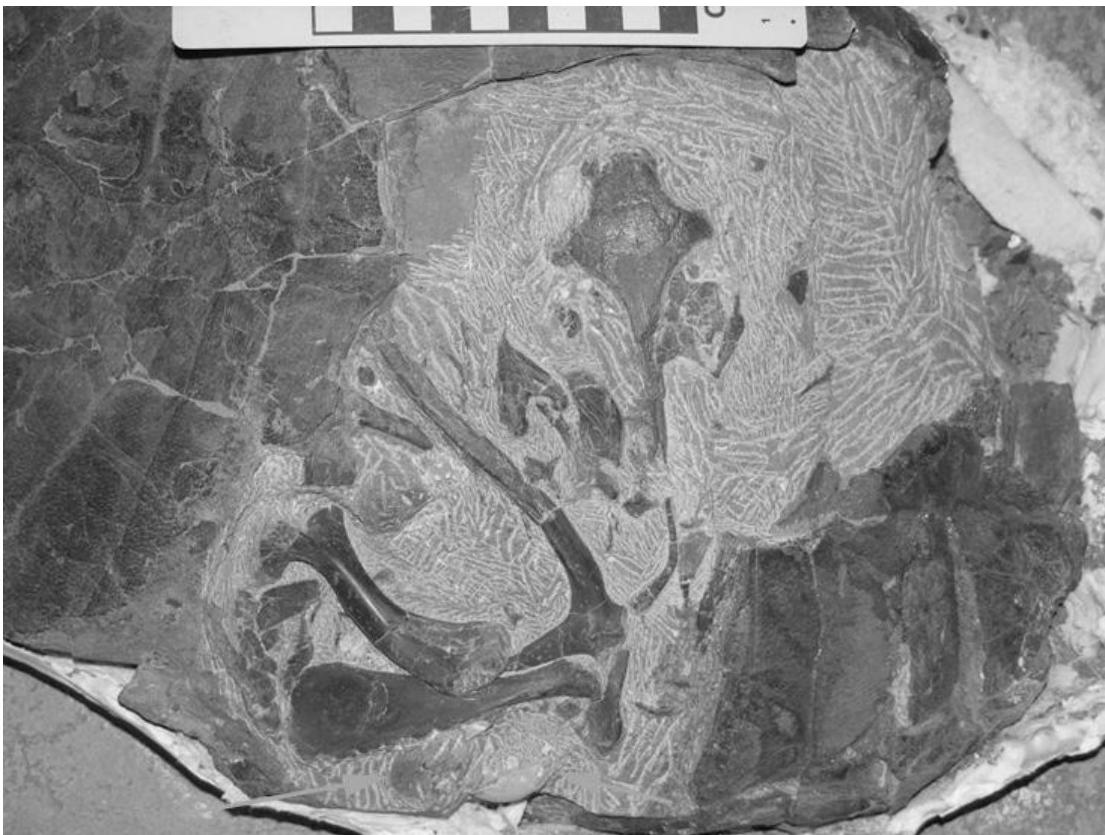


Figure 34. UMNH VP 16868, *Adocus* with skeleton and eggs, the latter are visible in the bottom center of the photo (yellow arrows). Scale = 10 cm.

macrovertebrate assemblages documented in previous published summaries (see appendix). As of now, the Kaiparowits holds the record for most diverse late Campanian assemblages of turtles, mammals, squamates, and crocodylians in North America and is rapidly closing the gap with the diverse dinosaur assemblages known from the Dinosaur Park Formation (Dinosaur Provincial Park, Alberta, Canada). New discoveries continue to add fossil materials to previously documented macrovertebrate taxa, permitting more thorough comparison and phylogenetic evaluation, and add new forms to the overall assemblage. This includes many new, exquisitely preserved crocodyliform specimens that expand the documented diversity and completeness of the group: (1) several associated pterosaur specimens that radically enhance the non-marine record of pterosaurs; and (2) new dinosaur materials that include several specimens of a new chasmosaurine

ceratopsian, two new genera of ankylosaur (Wiersma, 2016), and a possible small lambeosaurine hadrosaurid. These new finds, coupled with ongoing efforts to document the microvertebrate record, the plant macrofossil record, the invertebrate fossil record, and the geological record of the Kaiparowits Formation, promise to make it among the best-documented and understood terrestrial ecosystems in the Mesozoic. Comparison of the Kaiparowits vertebrate assemblage to contemporaneous faunas from Dinosaur Park Formation have documented significant differences in vertebrate taxa. Differences are attributed to possible physiographic barriers (e.g., Sampson and others, 2010; Gates and others, 2012) or climatic/floral differences (e.g., Miller and others, 2013; Nydam and others, 2013).

End of Day 2, return to Tropic, Utah.

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Figure 35. View looking west over the Blues from the upper view point along SR 12. Mostly the lower 400 m of the Kaiparowits Formation is seen from this view.

DAY 3: CRETACEOUS-PALEOGENE BOUNDARY IN SOUTHERN UTAH

0.0 miles – Start in Tropic at 200 North and SR 12.
 Proceed west on SR 12.

7.2 miles – Junction of SR 12 and SR 22 (Johns Valley Road). Turn right (north) on SR 22 and proceed north.

20.6 miles – Junction with SR 17 (Old Escalante Road). Turn right (east) and proceed east.

23.3 miles – **STOP 16. K-PG BOUNDARY AND THE CANAAN PEAK FORMATION:** The more resistant beds of the Canaan Peak Formation (figure 36) are

well exposed on this general stretch of SR17. The observable lithosomes are completely typical for the formation, and consist of trough cross-bedded pebble and cobble conglomerate with distinctive black chert clasts and other rocks derived from the lower Paleozoic siliceous strata of the Sevier fold and thrust belt as well as the earlier Antler foreland detritus. Jurassic and Early Cretaceous age volcanic clasts ranging in composition from rhyolite to andesite can locally make up as much as 30% of the total rock (Schmitt and others, 1991). The type section is located 30 km to the south (Bowers, 1972), on the south side of Canaan Peak, where it rests with slight angular unconformity on the Kaiparowits Formation and contains an identical clast composition (Schmitt and others, 1991). Goldstrand (1992) subse-

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Figure 36. Conglomerate and cross-stratified sandstone of the Canaan Peak Formation exposed in Horse Canyon, north of SR 17.

quently recognized an upper unit in the Canaan Peak which completely lacks volcanic clasts and is instead dominated by more proximally derived Paleozoic and Mesozoic sedimentary clasts from the Wah Wah thrust system. Given the similar composition of this upper Canaan Peak unit with the Grand Castle Formation in its type section (western Markagunt Plateau), these units were correlated and the term Grand Castle was extended into the Table Cliffs area by Goldstrand (1992). All of this pre-supposed that the Grand Castle in its type section was actually Paleogene (post-Kaiparowits Formation) in age. Now that the entire type Grand Castle Formation as originally conceived by Goldstrand can be demonstrated to be both Cretaceous and pre-Kaiparowits Formation in age (lower and middle Campanian [Biek and others, 2015]), use of the term Grand Castle in the Table Cliffs area should be abandoned. Based on gross clast composition, this locally occurring volcanic

clast-free lithosome in the Table Cliffs area may be genetically related to the overlying Pine Hollow Formation, but this needs further work.

Surprisingly, the areal extent of the Canaan Peak Formation is fairly limited, given its resistant nature and substantial thickness. Over most of the region the Cretaceous-Paleogene boundary represents a much more substantial hiatus (figure 14). Unequivocal Canaan Peak is known with certainty only east of the Paunsaugunt fault, around the Table Cliffs and Canaan Peak. However, it was obviously once much more widespread as current directions indicate a source area to the west and southwest (Schmitt and others, 1991).

The precise age of the Canaan Peak Formation proper is unknown as it has not yielded any age diagnostic faunal data or datable ash beds. Paleocene palynological assemblages (Goldstrand, 1990) have been reported from the upper volcanic-clast-free unit (Grand Castle of

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Goldstrand, 1992). If these palynology data are correct, then the Canaan Peak, as we define it here (excluding the non-volcanic clast-bearing part), can only be constrained as post middle upper Campanian to Paleocene. Eric Roberts (James Cook University, oral communication, 2013) has observed dinosaur bone in the lower portion of the Canaan Peak near the type section. However, it is unknown at this time whether this represents contemporaneous bone or elements reworked from the underlying Kaiparowits Formation.

The volcanic clast content of the Canaan Peak Formation ties it genetically to the underlying Kaiparowits Formation and strongly differentiates it from all overlying units (Larsen and others, 2010). From a strictly event-oriented view, since Laramide uplift completely removed the Canaan Peak and Kaiparowits Formations from the Paunsaugunt Plateau region, mostly likely in the late Paleocene or early Eocene (i.e., pre-Claron), it seems reasonable to assume that the volcanic lithic-rich Kaiparowits and Canaan Peak Formations occupy a space in time closer to each other than the Canaan Peak would with the Pine Hollow Formation because the Pine Hollow is compositionally very close to the Claron Formation (Larsen, 2007). As such, the Canaan Peak Formation, which could be Campanian-Maastrichtian in age, could also locally span the Cretaceous-Paleogene boundary.

End of Field Trip

ACKNOWLEDGEMENTS

We would like to thank the reviewers for making substantial improvements to the manuscript and the Geology of Intermountain West editors for assistance with the editing. We would also like to thank the Bureau of Land Management—Grand Staircase-Escalante National Monument for support during the writing of this paper, and also supporting much of the paleontological research in the Kaiparowits Basin that has been undertaken since 1996.

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APPENDIX

LATE CRETACEOUS VERTEBRATE FAUNAL LISTS FOR SOUTHERN UTAH

Background

Although the total number of taxa is known to be higher in every single Cretaceous formation of southern Utah, these faunal lists were generated only from published papers that documented specific specimens from specific localities with certain taxonomic assignments. Taxa listed in undocumented faunal lists (e.g., Eaton, 1999; Eaton and others, 1999a, 1999b) or overly broad taxonomic assignments are not included. As such, we only list the published turtle fauna from Hutchison and others (2013, Kaiparowits Formation) and Holroyd and Hutchison (2016, Wahweap Formation) even though turtle remains are common in nearly every formation. Similarly, a large number of additional dinosaur taxa are known from the Wahweap and Kaiparowits Formations, but either the specimens have never been described or the material is not specifically diagnostic. Irmis and others (2013) described the crocodyliform fauna at the order-suborder level and generally did not provide locality information for specimens; however, two taxa at lower levels were described from the Kaiparowits Formation, and since fossils are only known from that formation on the Kaiparowits Plateau, those are included below. The fish described by Brinkman and others (2013) are from a limited number of localities and are only recorded in the faunal lists from the specific plateau from which the specimens are documented. As such, there is a large list of fish represented from the Wahweap Formation of the Paunsaugunt Plateau, but these were not extended to the Wahweap Formation of the Kaiparowits Plateau as there is no documentation for that presented in Brinkman and others (2013). In the faunal lists, names, and years in parentheses cite the original publication naming that taxon, whereas those citations preceded by “in” merely refer to a source that documents the taxon in southern Utah. For nearly all macrovertebrates, the reference is the same as the original paper naming the taxon.

Cretaceous Vertebrate Faunas of Cedar Canyon Markagunt Plateau

Naturita Formation, Cenomanian (Localities: UMNH VP 161, 162)
Allocaudata
 Albanerpetontidae
 Gen. and sp. indet. (in Gardner and Demar, 2013)
Anura
 Family incertae sedis
 Gen. and sp. indet. (in Roček and others, 2010)
Squamata
 Boreoteiioidea
 Bicuspidon smikros (in Nydam, 2013)
Scincomorpha
 Contogenidae
 Utahgenys antongai (in Nydam, 2013)
 Paramacellobid/Cordylid grade
 Morphotype A (in Nydam, 2013)
 Morphotype B (in Nydam, 2013)
Anguimorpha
 Family incertae sedis
 Gen. and sp. indet. (in Nydam, 2013)
Multituberculata
 Family incertae sedis – *Paracimexomys* group
 Gen. and sp. indet. (in Eaton, 2009)
 cf. *Paracimexomys* sp. (in Eaton, 2009)
 Cedaramys minimus (in Eaton, 2009)
 Dakotamys malcolmi (in Eaton, 2009)
Cimolodontidae
 Gen. and sp. indet. (in Eaton, 2009)
?Cimolodontidae
 Gen. and sp. indet. (in Eaton, 2009)
Symmetrodonta
 Spalacotheriidae
 Gen. and sp. indet. (in Eaton, 2009)
Boreosphenida
 Family incertae sedis
 Gen. and sp. indet. (in Eaton, 2009)
Marsupialia
 “Alphadontidae”
 Eoalphadon woodburnei (in Eaton, 2009)
 ?Eoalphadon sp. (in Eaton, 2009)

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John Henry Member (Coniacian?), Straight Cliffs Formation (Localities: MNA 1260/UMNH VP 8, 9)

Elasmobranchii

 Lonchidiidae

Lonchidion sp. (in Kirkland and others, 2013)

Neoselachii

 Ginglymostomatidae

Cantioscyllium markaguntensis (Kirkland and others, 2013)

Neopterygii

 Semionotidae

Lepidotes sp. indet. (in Brinkman and others, 2013)

 Pycnodontidae

Coelodus sp. (in Brinkman and others, 2013)

Teleostii

 Otophysi Order and family indet.

 Gen. and sp. indet. (in Brinkman and others, 2013)

 Acanthomorpha Order and family indet.

 Gen. and sp. indet. (in Brinkman and others, 2013)

Urodela

 Scapherpetontidae

 Gen. and sp. indet. (in Gardner and Demar, 2013)

 Family incertae sedis

 Gen. and sp. indet. (in Gardner and Demar, 2013)

Anura

 Family incertae sedis

 Gen. and sp. indet. (in Roček and others, 2010)

Multituberculata

 Family incertae sedis – *Paracimexomys* group

Cedaromys sp. (in Eaton, 2006a)

Marsupialia

 Family “Alphadontidae”

 ? *Varalphodon* sp. (in Eaton, 2006a)

Eutheria

 Order and family incertae sedis

 Gen. and sp. indet. (in Eaton, 2006a)

“Wahweap” Formation (basal, lower? Campanian) (Locality: UMNH VP 10/MNA 1417)

Allocaudata

 Albanerpetontidae

 Gen. and sp. indet. (in Gardner and Demar, 2013)

Anura

 Family incertae sedis

 Gen. and sp. indet. (in Roček and others, 2010)

Multituberculata

 Family incertae sedis – *Paracimexomys* group

 cf. *Paracimexomys* sp. (in Eaton, 2006a)

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Bryceomys sp. (in Eaton, 2006a)

Cedaromys sp. cf. *C. hutchisoni* (in Eaton, 2006a)

Cedaromys sp. (in Eaton, 2006a)

?*Cimoxomys* sp. (in Eaton, 2006a)

Cimolomyidae

Cimolomys sp. (in Eaton, 2006a)

?*Cimolomys* sp. (in Eaton, 2006a)

Cimolodontidae

Cimolodon wardi (in Eaton, 2006a)

Cimolodon similis (in Eaton, 2006a)

Cimolodon sp. cf. *C. nitidus* (in Eaton, 2006a)

Neoplagiaulacidae

Mesodma sp. cf. *M. minor* (in Eaton, 2006a)

Trechnotheria

Spalacotheriidae

Symmetrodontoides sp. cf. *S. foxi* (Eaton, 2006a)

Marsupialia

Order and family incertae sedis

cf. *Anchistodelphys* sp. (in Eaton, 2006a)

“Alphadontidae”

cf. *Varalphadon* sp. (in Eaton, 2006a)

cf. *Protalphadon* sp. (in Eaton, 2006a)

Eoalphadon sp. cf. *E. clemensi* (in Eaton, 2006a, see Eaton, 2009)

Eoalphadon sp. (in Eaton, 2006a, see Eaton, 2009)

cf. *Turgidodon* sp. (in Eaton, 2006a)

?Pediomyidae

??"*Pediomys*" sp. (in Eaton, 2006a)

Boreosphenida

Picopsidae

Picopsis sp. (in Eaton, 2006a)

cf. *Picopsis* sp. A (in Eaton, 2006a)

cf. *Picopsis* sp. B (in Eaton, 2006a)

“Wahweap” Formation (high, Campanian?) (Locality: UMNH VP 11)

Urodela

Family incertae sedis

Nezpercius dodsoni (in Gardner and Demar, 2013)

Anura

Family incertae sedis

Scotiophryne pustulosa (in Roček and others, 2010; Gardner and Demar, 2013)

Gen. and sp. indet. (in Roček and others, 2010)

Multituberculata

Family incertae sedis – *Paracimexomys* group

Cedaromys sp. (in Eaton, 2006a)

Cimolomyidae

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Meniscoessus sp. cf. *M. intermedius* (in Eaton, 2006a)

Cimolomys sp. (in Eaton, 2006a)

?*Cimolomys* sp. (in Eaton, 2006a)

Cimolodontidae

Cimolodon sp. cf. *C. similis* (in Eaton, 2006a)

Marsupialia

“Alphadontidae”

Gen. and sp. indet. (in Eaton, 2006a)

Protalphadon sp. (in Eaton, 2006a)

?*Protalphadon* sp. (in Eaton, 2006a)

Eoalphadon sp. cf. *E. clemensi* (in Eaton, 2006a, see Eaton, 2009)

“Pediomyidae”

Gen. and sp. indet. (in Eaton, 2006a)

“*Pediomys*” sp. near “*P.* exiguous” (in Eaton, 2006a)

?*Aquiladelphis laurae* (in Eaton, 2006a)

Cretaceous Vertebrate Faunas of the Paunsaugunt Plateau

Naturita Formation, Cenomanian (Locality: UMNH VP 123/MNA 939)

Anura

Family, Gen. and sp. indet. (in Roček and others, 2010)

Multituberculata

Cimolodontidae

Gen. and sp. indet. (in Eaton, 1995)

Family incertae sedis – *Paracimexomys* group

Paracimexomys sp. cf. *P. robisoni* (in Eaton, 1995)

Paracimexomys sp. (in Eaton, 1995)

cf. *Paracimexomys* sp. (in Eaton, 1995)

Dakotamys malcolmi (in Eaton, 1995)

Theria

Family, Gen. and sp. indet. (in Eaton, 1993b)

Marsupialia

“Alphadontidae”

Eoalphadon lillegraveni (in Eaton, 1993b as “*Alphadon*” *lillegraveni*)

Eoalphadon sp. (in Eaton, 1993b as “*Alphadon*” sp.)

Family incertae sedis

Pariadens kirklandi (in Eaton, 1993b)

John Henry Member (basal, Coniacian), Straight Cliffs Formation (Localities: UMNH VP 417, 823, 856, 1064)

Elasmobranchii

Hybodontidae

Hybodus sp. (in Kirkland and others, 2013)

Lonchidiidae

Lonchidion sp. (in Kirkland and others, 2013)

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Anura

Family incertae sedis

Gen. and sp. indet. (in Roček and others, 2010)

Dinosauria

Ornithopoda

Iguanodontia gen. and sp. indet. (in Gates and others, 2013)

Multituberculata

Cimolodontidae

Mesodma sp. cf. *M. minor* (in Eaton, 2013)

John Henry Member (Santonian), Straight Cliffs Formation (Localities: UMNH VP 419, 420, 424, 426, 427, 569, 781, 799, 821, 843, 1144, 1156)

Elasmobranchii

Hybodontidae

Hybodus sp. (in Kirkland and others, 2013)

Neopterygii

Lepisostidae

Lepisosteus sp. indet. (in Brinkman and others, 2013)

Neopterygii

Semionotidae

Lepidotes sp. indet. (in Brinkman and others, 2013)

Pycnodontidae

Micropycnodon sp. (in Brinkman and others, 2013)

Amiidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Teleostii

Hiodontidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Elopiformes Family indet.

Gen. and sp. indet. (in Brinkman and others, 2013)

Sorbinichthyidae

Diplomystus sp. (in Brinkman and others, 2013)

Otophysi Order and family indet.

Gen. and sp. indet. (in Brinkman and others, 2013)

Euteleostei Order and family indet.

Gen. and sp. indet. U-4 (in Brinkman and others, 2013)

Acanthomorpha Order and family indet.

Gen. and sp. indet. (in Brinkman and others, 2013)

Allocaudata

Albanerpetontidae

Gen. and sp. indet. (in Gardner and Demar, 2013)

cf. *Albanerpeton nexusum* (Gardner and Demar, 2013)

Urodela

Scapherpetontidae

Scapherpeton sp. (in Gardner and Demar, 2013)

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Batracoauroididae

- Opistotriton* sp. (in Gardner and Demar, 2013)
- Gen. and sp. indet. (in Gardner and Demar, 2013)

Sirenidae

- Habrosaurus* sp. (in Gardner and Demar, 2013)

Family incertae sedis

- Gen. and sp. nov. (in Gardner and Demar, 2013)

Anura

Family incertae sedis

- Scotiophryne pustulosa* (in Roček and others, 2010, Gardner and Demar, 2013)
- Gen. and sp. indet. (in Roček and others, 2010)

Scincomorpha

Paramacelolidid/Cordylid grade

- Monocnemodon syphakos* (in Nydam, 2013)

Anguimorpha

Family incertae sedis

- cf. *Colpodontosaurus* sp. (in Nydam, 2013)

Platynota

Family incertae sedis

- Morphotype B (in Nydam, 2013)

- Morphotype C (in Nydam, 2013)

Autarchoglossa

Family incertae sedis

- Morphotype D (in Nydam, 2013)

Scincomorpha

Family incertae sedis

- Gen. and sp. indet. (in Nydam, 2013)

Serpentes

Family incertae sedis

- Coniophis* sp. (in Nydam, 2013)

Dinosauria

Nodosauridae

- Gen and sp. indet. (in Loewen and others, 2013a)

Triconodonta

Triconodontidae

- Gen. and sp. indet. (in Eaton, 2013)

- cf. *Alticonodon* sp. (in Eaton, 2013)

Multituberculata

Family incertae sedis – *Paracimexomys* group

- Dakotamys shakespearei* (in Eaton, 2013)

- Cedaromys* sp. cf. *C. hutchisoni* (in Eaton, 2013)

Neoplagiulaclidae

- Mesodma* sp. cf. *M. minor* (in Eaton, 2013)

- Mesodma* sp. (in Eaton, 2013)

- ?*Mesodma* sp. (in Eaton, 2013)

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Cimolodontidae

- Cimolodon* sp. cf. *C. foxi* (in Eaton, 2013)
- Cimolodon similis* (in Eaton, 2013)
- Cimolodon* sp. cf. *C. similis* (in Eaton, 2013)
- ?*Cimolodon* sp. (in Eaton, 2013)

Cimolomyidae

- Cimolomys* sp. A (in Eaton, 2013)
- Cimolomys* sp. B (in Eaton, 2013)
- ?*Cimolomys* sp. A (in Eaton, 2013)
- ?*Cimolomys* sp. B (in Eaton, 2013)

Trechnotheria

Spalacotheriidae

- ?*Spalacotheridium* sp. (in Eaton, 2013)
- Symmetrodontoides* sp. (in Eaton, 2013)

Marsupialia

- “Didelphomorpha” - Family incertae sedis
- Gen. and sp. indet. (in Eaton, 2013)
- Apitodon* sp. cf. *A. exiguum* (in Eaton, 2013)
- cf. “*Anchistodelphys*” sp. (in Eaton, 2013)

“Alphadontidae”

- ?*Varalphadon* sp. (in Eaton, 2013)

Stagodontidae

- Eodelphis* sp. (in Eaton, 2013)

Pediomyidae

- Gen. and sp. indet. (in Eaton, 2013)
- ?*Leptalestes* sp. (in Eaton, 2013)

Wahweap Formation, Campanian (Localities: UMNH VP 61, 77, 78, 80, 83, 807, 792, 1073, 1074; MNA 1073, 1074)

Neoselachii

- Hemiscyllidae
- Chiloscyllium missouriense* (in Kirkland and others, 2013)

Batomorphii

- Rhinobatoidea - Family incertae sedis
- Cristomylus cifellii* (Kirkland and others, 2013)

Sclerorhynchiformes

- Sclerorhynchiidae
- Columbusia deblieuxi* (Kirkland and others, 2013)

Neopterygii

- Lepisostidae
- Lepisosteus* sp. indet. (in Brinkman and others, 2013)
- Semionotidae
- Lepidotes* sp. indet. (in Brinkman and others, 2013)
- Pycnodontidae
- Micropycnodon* sp. (in Brinkman and others, 2013)

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Actinopterygii

Albulidae

Parabula sp. (in Brinkman and others, 2013)

Otophysi Order and family indet.

Gen. and sp. indet. (in Brinkman and others, 2013)

Acanthomorpha Order and family indet.

Gen. and sp. indet. (in Brinkman and others, 2013)

Allocaudata

Albanerpetontidae

Gen. and sp. indet. (in Gardner and Demar, 2013)

Urodela

Scapherpetontidae

Scapherpeton tectum in Gardner and Demar, 2013

Batracosauroididae

Opistotriton kayi (in Gardner and Demar, 2013)

Family incertae sedis

Nezpercius dodsoni (in Gardner and Demar, 2013)

Gen. and sp. nov. (in Gardner and Demar, 2013)

Anura

Family incertae sedis

Scotiophryne pustulosa (in Roček and others, 2010)

Gen. and sp. indet. (in Roček and others, 2010)

Multituberculata

Family incertae sedis – *Paracimexomys* group

Paracimexomys sp. (in Eaton, 1993b)

?*Paracimexomys* sp. (in Eaton, 2013)

Cedaromys sp. cf. *C. hutchisoni* (in Eaton, 2013)

?*Cimexomys gregoryi* (in Eaton, 1993b)

Gen. and sp. indet. (in Eaton, 2002)

Neoplagiaulacidae

Mesodma sp. cf. *M. minor* (in Eaton, 2013)

Mesodma sp. cf. *M. archibaldi* (in Eaton, 2002, 2013)

Mesodma sp. cf. *M. formosa* (in Eaton, 1993b, 2013)

Mesodma sp. cf. *M. hensleghi* (in Eaton, 1993b)

Mesodma sp. (in Eaton, 1993b)

Cimolodontidae

Cimolodon similis (in Eaton, 2002)

Cimolodon sp. cf. *C. nitidus* (in Eaton, 1993b)

Cimolodon sp. cf. *C. foxi* (in Eaton, 2013)

?*Cimolodon* sp. (Eaton, 1993b)

Cimolomyidae

Cimolomys milliensis (in Eaton, 1993b)

Cimolomys sp. (in Eaton, 2013)

?*Cimolomys* sp. (in Eaton, 2013)

?*Cimolomys* sp. B (in Eaton, 2002)

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Meniscoessus sp. (in Eaton, 2013)

Trechnotheria

Spalacotheriidae

Symmetrodontoides foxi (in Eaton, 1993b)

Marsupialia

Order and Family incertae sedis

cf. *Iugomortiferum* sp. (in Eaton, 2013)

Gen. and sp. indet. A (in Eaton, 2013)

Gen. and sp. indet. B (in Eaton, 2013)

cf. *Apistodon* sp. (in Eaton, 2013)

“Alphadontidae”

Alphadon sp. cf. *A. wilsoni* (in Eaton, 1993b)

Alphadon sp. cf. *A. attaragos* (in Eaton, 1993b)

Turgidodon sp. cf. *T. russelli* (*Alphadon* sp. cf. *A. russelli* in Eaton, 1993b)

Turgidodon sp. (in Eaton, 1993b)

Varalphadon sp. cf. *V. creber* (in Eaton, 2013)

cf. *Varalphadon* sp. (in Eaton, 2013)

Pediomyidae

Gen. and sp. indet. (in Eaton, 2013)

Cretaceous Vertebrate Faunas of the Kaiparowits Plateau

Naturita Formation, Cenomanian (Localities: UMNH VP 27/MNA 1067/OMNH V808; UMNH VP 804)

Batomorphii

Rhinobatoidea Family incertae sedis

Cristomylus bulldogensis (Kirkland and others, 2013)

Pseudomyledaphus sp. (in Kirkland and others, 2013)

Elasmobranchii

Hybonontidae

Hybodus sp. (in Kirkland and others, 2013)

Lonchidiidae

Lonchidion sp. (in Kirkland and others, 2013)

Neopterygii

Semionotidae

Lepidotes sp. (in Brinkman and others, 2013)

Pycnodontidae

Coelodus sp. (in Brinkman and others, 2013)

Amiidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Teleostei

Osteoglossomorpha family indet.

Coriops sp. (in Brinkman and others, 2013)

Hiodontidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Elopiformes Family indet.

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- Gen. and sp. indet. (in Brinkman and others, 2013)
- Ellimmichthyiformes Family indet.
 - Gen. and sp. indet. type LvD (in Brinkman and others, 2013)
 - Gen. and sp. indet. type U-7 (in Brinkman and others, 2013)
- Sorbinichthyidae
 - Diplomystus* sp. (in Brinkman and others, 2013)
- Euteleostei Order and family indet.
 - Gen. and sp. indet. U-4 (in Brinkman and others, 2013)
- Sarcopterygii
 - Ceratodontiformes
 - Ceratodus gustasoni* (Kirkland, 1987)
- Allocaudata
- Albanerpetontidae
 - cf. *Albanerpeton nexuosa* (in Gardner and Demar, 2013)
- Urodela
 - Scapherpetontidae
 - Gen and sp. indet. (in Gardner and Demar, 2013)
 - Batracosauroididae
 - Gen. and sp. nov. (in Gardner and Demar, 2013)
- Anura
 - Family incertae sedis
 - Gen. and sp. indet. (in Roček and others, 2010)
- Squamata
 - Boreoteiioidea
 - Bicuspidon smikros* (in Nydam, 2013)
 - Scincomorpha
 - Paramacelolidid/Cordylid grade
 - Dakotasaurus gillettorum* (in Nydam, 2013)
 - Morphotype C (in Nydam, 2013)
 - Webbsaurus lofgreni* (in Nydam, 2013)
 - Family indet.
 - Morphotype D (in Nydam, 2013)
 - ?Scincomorpha
 - Family incertae sedis
 - Gen. and sp. indet. (in Nydam, 2013)
 - Anguimorpha
 - aff. Xenosauridae
 - Cnodontosaurus suchockii* (in Nydam, 2013)
 - Platynota
 - Family indet.
 - Morphotype E (in Nydam, 2013)
 - Anguimorpha
 - Family incertae sedis
 - Gen. and sp. indet. (in Nydam, 2013)
 - Serpentes

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Family incertae sedis

Coniophis sp. (in Nydam, 2013)

Multituberculata

Family incertae sedis – *Paracimexomys* group

Paracimexomys sp. cf. *P. robisoni* (in Eaton, 1995)

Paracimexomys sp. (in Eaton, 1995)

cf. *Paracimexomys* sp. (in Eaton, 1995)

Dakotamys malcolmi (in Eaton, 1995)

?*Dakotamys* sp. (in Eaton, 1995)

Gen. and sp. indet. A (in Eaton, 1995)

Gen. and sp. indet. B (in Eaton, 1995)

Cimolodontidae

Cimolodon sp. cf. *C. similis* (in Eaton, 1995)

Gen. and sp. indet. (in Eaton, 1995)

?Boreosphenida

Order and family incertae sedis

Gen. and sp. indet. (in Eaton, 1993a)

Dakotadens morrowi (in Eaton, 1993a)

Dakotadens sp. (in Eaton, 1993a)

Marsupialia

Family “Alphadontidae”

Eoalphadon clemensi (in Eaton, 1993a as “*Alphadon*” *clemensi*)

Eoalphadon lillegraveni (in Eaton, 1993a as “*Alphadon*” *lillegraveni*)

Eoalphadon sp. (in Eaton, 1993a as “*Alphadon*” sp.)

Protalphadon sp. (in Eaton, 1993a)

Gen. and sp. indet. (in Eaton, 1993a)

Family indet.

Pariadens kirklandi (Cifelli and Eaton, 1987)

Tropic Shale (Late Cenomanian-Middle Turonian)

Elasmobranchii

Mitsukurinidae

Scapanorhynchus raphiodon (in Albright and others, 2013)

Anacoracidae

Squalicorax curvatus (in Albright and others, 2013)

Cretoxyrhinidae

Cretoxyrhina mantelli (in Albright and others, 2013)

Cretolamna appendiculata (in Albright and others, 2013)

Sclerorhyncoidei

cf. *Ptychotrygon* sp. (in Albright and others, 2013)

Ptychodontidae

Ptychodus decurrens (in Albright and others, 2013)

Ptychodus cf. *P. mammillaris* (in Albright and others, 2013)

Ptychodus whipplei (in Albright and others, 2013)

Ptychodus occidentalis (in Albright and others, 2013)

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Ptychodus anomus (in Albright and others, 2013)

Ptychodus sp. indet. (in Albright and others, 2013)

Neopterygii

Pycnodontidae

Gen. and sp. indet. (in Albright and others, 2013)

Actinopterygii

Ichthyodectidae

Gillicus arcuatus (in Albright and others, 2013)

Ichthyodectes ctenodon (in Albright and others, 2013)

Ichthyodectes cf. *I. ctenodon* (in Albright and others, 2013)

Xiphactinus cf. *X. audax* (in Albright and others, 2013)

Testudinata

Protostegidae

Desmatochelys lowi (in Albright and others, 2013)

Gen. and sp. indet. (in Albright and others, 2013)

Family incertae sedis

Naomichelys sp. (in Albright and others, 2013)

Sauropterygia

Pliosauridae

Brachauchenius lucasi (Albright and others, 2007a)

Polycotylidae

Eopolycotylus rankini (Albright and others, 2007b)

Dolichorhyncops tropicensis Schmeisser McKean, 2012

Palmulasaurus quadratus (Albright and others, 2007b)

Trinacromerum cf. *T. bentonianum* (in Albright and others, 2013)

Dinosauria

Therizinosauridae

Nothronychus graffami (Zanno and others, 2009)

Smoky Hollow Member (Turonian), Straight Cliffs Formation (Localities: UMNH VP 129/MNA 995/OMNH V843; OMNH V4, 60, 1404)

Batomorphii

Rhinobatoidea (family incertae sedis)

Cristomylus sp. cf. *C. bulldogensis* (in Kirkland and others, 2013)

Osteichthyes-Neopterygii

Lepisostidae

Lepisosteus sp. (in Brinkman and others, 2013)

Semionotidae

Lepidotes sp. (in Brinkman and others, 2013)

Pycnodontidae

Coelodus sp. (in Brinkman and others, 2013)

Amiidae

Gen. and sp. indet. (in Brinkman and others, 2013)

?*Melvius* sp. (in Brinkman and others, 2013)

Teleostii

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Hiodontidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Elopiformes Family incertae sedis

Gen. and sp. indet. (in Brinkman and others, 2013)

Ellimmichthyiformes Family incertae sedis.

Gen. and sp. indet. type U-7 (in Brinkman and others, 2013)

Otophysi Order and family incertae sedis

Gen. and sp. indet. (in Brinkman and others, 2013)

Euteleostei Order and family incertae sedis

Gen. and sp. indet. U-4 (in Brinkman and others, 2013)

Order and family incertae sedis

Gen. and sp. indet. type HvB (in Brinkman and others, 2013)

Allocaudata

Albanerpetontidae

Albanerpeton cifellii (in Gardner, 1999)

cf. *Albanerpeton nexoosum* (in Gardner and Demar, 2013)

Gen. and sp. indet. (in Gardner and Demar, 2013)

Urodela

Batracosauroididae

Gen. and sp. nov. (in Gardner and Demar, 2013)

Family incertae sedis

Gen. and sp. nov. (in Gardner and Demar, 2013)

Gen. and sp. indet. (in Gardner and Demar, 2013)

Anura

Family incertae sedis

Gen. and sp. indet. (in Roček and others, 2010)

Scinocomorpha

Polyglyphanodontini

Dicothodon cifellii (in Nydam and others, 2007)

Chamops sp. cf. *C. signus* (in Nydam, 2013)

Contogeniidae

Utahgenys evansi (in Nydam, 2013)

Paramacelolid/Cordylid grade

Morphotype A-H (in Nydam, 2013)

Anguimorpha

Anguidae

aff. *Odaxosaurus* sp. (in Nydam, 2013)

aff. Xenosaurida

Cnodontosaurus sp. (in Nydam, 2013)

Platynota

Family incertae sedis

Morphotype I-J (in Nydam, 2013)

Anguimorpha

Family incertae sedis

Gen. and sp. indet. (in Nydam, 2013)

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Serpentes

Family incertae sedis

Coniophis sp. (in Nydam, 2013)

Dinosauria

Ornithopoda

Iguanodontia gen. and sp. indet. (in Gates and others, 2013)

Multituberculata

?Taeniolabidoidea Family incertae sedis

Gen. and sp. indet. (in Eaton, 1995)

Suborder and family incertae sedis - *Paracimexomys* group

Paracimexomys sp. cf. *P. robisoni* (in Eaton, 1995)

Bryceomys fumosus (in Eaton, 1995)

Bryceomys sp. cf. *B. fumosus* (in Eaton, 1995)

Bryceomys hadrosus (in Eaton, 1995)

Bryceomys sp. (in Eaton, 1995)

Symmetroonta

Family incertae sedis

Gen. and sp. indet. (in Cifelli and Gordon, 1999)

Spalacotheriidae

Symmetrodontoides oligodontos (in Cifelli and Gordon, 1999)

Spalacotheridium mckennai (in Cifelli and Gordon, 1999)

Aegialodontia

Deltatheridiidae

Gen. and sp. indet. (in Cifelli, 1990a)

Family incertae sedis

Gen. and sp. indet. (in Cifelli, 1990a)

Marsupalia

Family incertae sedis

?*Varalphadon delicates* (in Cifelli, 1990a)

?Stagodontidae

Gen. and sp. indet. (in Cifelli, 1990a)

John Henry Member (basal - Coniacian), Straight Cliffs Formation (Localities: OMNH V856; UMNH VP 663)

Batomorphii

Rhinobatoidea Family incertae sedis

Pseudomyledaphus madseni (Kirkland and others, 2013)

Allocaudata

Albanerpetontidae

Gen. and sp. indet. (in Gardner and Demar, 2013)

Urodela

Scapherpetontidae

Scapherpeton tectum (in Gardner and Demar, 2013)

Gen. and sp. indet. (in Gardner and Demar, 2013)

John Henry Member (Santonian), Straight Cliffs Formation (Localities: UMNH VP 98, 99, 567; OMNH V27; MNA 706)

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Neoselachii

Ginglymostomatidae

Cantioscyllium markaguntensis (Kirkland and others, 2013)

Batomorphii

Rhinobatoidea Family incertae sedis

Pseudomyledaphus madseni (Kirkland and others, 2013)

Allocaudata

Albanerpetontidae

Gen. and sp. indet. (in Gardner and Demar, 2013)

Urodela

Batracosauroididae

Opistotriton kayi (in Gardner and Demar, 2013)

Gen. and sp. indet. (in Gardner and Demar, 2013)

Anura

Family incertae sedis

Gen. and sp. indet. (in Roček and others, 2010)

Scincomorpha

Paramacellobid/Cordylid grade

Monocnemodon syphakos (in Nydam, 2013)

Morphotype A (in Nydam, 2013)

Multituberculata

Family incertae sedis – *Paracimexomys* group

Cedaromys sp. cf. *C. hutchisoni* (in Eaton, 2006b)

Cedaromys sp. (in Eaton, 2006b)

Family incertae sedis

Gen. and sp. indet. (in Eaton, 2006b)

Neoplagiaulacidae

Mesodma sp. cf. *M. minor* (in Eaton, 2006b)

Cimolodontidae

Cimolodon foxi (in Eaton, 2006b)

Cimolodon sp. (in Eaton, 2006b)

?*Cimolodon* sp. (in Eaton, 2006b)

Cimolomyidae

?*Cimolomys* sp. (in Eaton, 2006b)

Theria

Spalacotheriidae

Spalacotherium sp. (in Eaton, 2006b)

Symmetrodontoides sp. cf. *S. oligodontos* (in Cifelli and Gordon, 1999)

Family incertae sedis

Potamotelses sp. (in Eaton, 2006b)

Picopsis sp. (in Eaton, 2006b)

Marsupialia

“Alphadontidae”

Alphadon sp. cf. *A. halleyi* (in Eaton, 2006b)

Varalphadon sp. (in Eaton, 2006b)

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?Stagodontidae

Gen. and sp. indet. (in Eaton, 2006b)

Family incertae sedis

?*Anchistodelphys* sp. (in Eaton, 2006b)

Gen. and sp. indet. (in Eaton, 2006b)

Wahweap Formation, Middle Campanian (Localities: OMNH V2, 8, 11, 16; UMNH VP 82, 130; MNA 455, 456, 702, 705, 707, 1015, 1294)

Elasmobranchii

Hybodontidae

Hybodus sp. (in Kirkland and others, 2013)

Lonchidiidae

Lonchidion sp. (in Kirkland and others, 2013)

Neoselachii

Ginglymostomatidae

Cantioscyllium estesi (in Kirkland and others, 2013)

Hemiscyllidae

Chiloscyllium missouriense (in Kirkland and others, 2013)

Batomorphii

Rhinobatoidea Family incertae sedis

Cristomylus cifellii (Kirkland and others, 2013)

Sclerorhynchiformes

Sclerorhynchiidae

Columbusia deblieuxi (Kirkland and others, 2013)

Texatrygon brycensis (Kirkland and others, 2013)

Osteichthyes-Neopterygii

Amiidae

Melvius cf. M. chauliodous (in Holroyd and Hutchison, 2016)

Lepisostidae

Gen. and sp. indet. (in Holroyd and Hutchison, 2016)

Actinopterygii

Polyodontidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Urodela

Batracosauroididae

Opistotriton kayi (in Gardner and Demar, 2013)

Family incertae sedis

Nezpercius dodsoni (in Gardner and Demar, 2013)

Anura

Family incertae sedis

Scotiophryne pustulosa (in Roček and others, 2010)

Gen. and sp. indet. (in Roček and others, 2010)

Testudines

Baenidae

Arvinochelys sp. (in Holroyd and Hutchison, 2016)

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Denazinamys nodosa (in Holroyd and Hutchison, 2016)

Neurankylus sp. (in Holroyd and Hutchison, 2016)

Nanhsiungchelyidae

Basilemys sp. (in Holroyd and Hutchison, 2016)

Trionychidae

Gen. and sp. indet. (in Holroyd and Hutchison, 2016)

Squamata

cf. Anguimorpha indet. (in Nydam, 2013)

Serpentes

Family incertae sedis

Coniophis sp. (in Nydam, 2013)

cf. Scincomorpha – Family incertae sedis

Morphotype A (in Nydam, 2013)

Gen. and sp. indet. (in Nydam, 2013)

Dinosauria-Saurischia

Theropoda-Tyrannosauridae

Lythronax argestes (Lowen and others, 2013c).

Dinosauria-Ornithischia

Ornithopoda-Hadrosauridae

Saurolophinae

Aristovus sp. (in Gates and others, 2013)

c.f. *Brachylophosaurus* sp. (in Gates and others, 2013)

Lambeosaurinae (crested hadrosaurs)

Adelophorus hutchisoni (Gates and others, 2014)

Ceratopsidae

Centrosaurinae

Diabloceratops eatoni (Kirkland and DeBlieux, 2010)

Machairaceratops cronusi (Lund and others, 2016)

“Wahweap centrosaurine C” (in Loewen and others, 2013b)

Pachcephalosauridae

Gen. and sp. indet. (in Evans and others, 2013)

Multituberculata

Family incertae sedis – *Paracimexomys* group

Gen. and sp. indet. (in Eaton, 2002)

?*Paracimexomys* sp. (in Eaton, 2002)

cf. *Paracimexomys* sp. A (in Eaton, 2002)

cf. *Paracimexomys* sp. B (in Eaton, 2002)

Bryceomys sp. cf. *B. fumosus* (in Eaton, 2002)

Cedaromys sp. (in Eaton, 2002)

cf. *Cedaromys* sp. (in Eaton, 2002)

?*Cimexomys* sp. cf. *C. antiquus* (in Eaton, 2002)

Neoplagiulaclidae

Mesodma sp. cf. *M. formosa* (in Eaton, 2002)

Mesodma sp. cf. *M. minor* (in Eaton, 2002)

Mesodma sp. cf. *M. archibaldi* (in Eaton, 2002)

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Cimolodontidae

- Cimolodon electus* (in Eaton, 2002)
- Cimolodon similis* (in Eaton, 2002)
- Cimolodon* sp. cf. *C. nitidus* (in Eaton, 2002)
- Cimolodon* sp. cf. *C. foxi* (in Eaton, 2002)
- Cimolodon* sp. (small) (in Eaton, 2002)

Cimolomyidae

- Cimolomys* sp. cf. *C. trochus* (in Eaton, 2002)
- ?*Cimolomys* sp. A (in Eaton, 2002)
- ?*Cimolomys* sp. B (in Eaton, 2002)
- ?*Cimolomys* sp. C (large) (in Eaton, 2002)
- Meniscoessus* sp. cf. *M. intermedius* (in Eaton, 2002)

Symmetroonta

Family incertae sedis

- Gen. and sp. indet. (in Cifelli and Gordon, 1999)

Spalacotheriidae

- Symmetrodontoides foxi* (in Cifelli and Madsen, 1986; Cifelli and Gordon, 1999)

Order and Family incertae sedis

- Zygiocuspis goldingi* (in Cifelli, 1990c)

Marsupialia

“Alphadontidae”

- Varalphadon crebreforme* (in Cifelli, 1990b)
- Varalphadon wahweapensis* (in Cifelli, 1990b)
- Gen. and sp. indet. (in Cifelli, 1990b)

?Marsupialia

Family incertae sedis

- Iugomortiferum thoringtoni* (in Cifelli, 1990b)
- cf. *Iugomortiferum* sp. (in Cifelli, 1990b)

Insectivora

?Nyctitheriidae

- Paranyctoides* sp. (in Cifelli, 1990e)

Kaiparowits Formation, Upper Campanian (Localities: OMNH V5, 6, 9, 61; UMNH VP 24, 25, 51, 54, 56, 108, 1078, 1268; MNA 453, 454, 458, 697, 704, 1004, 1310; UCM 83240; 83258; for turtle bearing localities see Hutchison and others, 2013)

Neoselachii

Hemiscyllidae

- Chiloscyllium missouriense* (in Kirkland and others, 2013)

Batomorphii

Rhinobatoidea Family incertae sedis

- Myleaphus bipartitus* (Kirkland and others, 2013)

Sclerorhynchiformes

Sclerorhynchiidae

- Columbusia debbieuxi* (Kirkland and others, 2013)

Osteichthyes-Neopterygii

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Semionotidae

Lepidotes sp. indet. (in Brinkman and others, 2013)

Amiidae

Gen. and sp. indet. (in Brinkman and others, 2013)

Lepisostidae

Lepisosteus sp. indet. (in Brinkman and others, 2013)

Teleostei

Osteoglossomorpha Family incertae sedis

Coriops sp. (in Brinkman and others, 2013)

Hiodontidae

Gen. and sp. indet. (in Brinkman, 2013)

Albulidae

Parabula sp. (in Brinkman and others, 2013)

Clupeiformes Family incertae sedis

Gen. and sp. indet. type G (in Brinkman and others, 2013)

Otophysi Order and family incertae sedis

Gen. and sp. indet. (in Brinkman and others, 2013)

Characiformes Family incertae sedis

Gen. and sp. indet. (in Brinkman and others, 2013)

Euteleostei Order and family incertae sedis

Gen. and sp. indet. U-4 (in Brinkman and others, 2013)

Esocoidea Family incertae sedis

Estesesox foxi (in Brinkman and others, 2013)

Estesesox sp. (in Brinkman and others, 2013)

Order and family incertae sedis

Gen. and sp. indet. type BvE (in Brinkman and others, 2013)

Acanthomorpha Order and family incertae sedis

Gen. and sp. indet. (in Brinkman and others, 2013)

Allocaudata

Albanerpetontidae

Albanerpeton galaktion (in Gardner and Demar, 2013)

Albanerpeton gracile (in Gardner and Demar, 2013)

Albanerpeton nexusum (in Gardner and Demar, 2013)

Urodela

Scapherpetontidae

Scapherpeton tectum (in Gardner and Demar, 2013)

Lisserpeton bairdi (in Gardner and Demar, 2013)

Batracosauroididae

Opistotriton kayi (in Gardner and Demar, 2013)

Prodesmondon copei (in Gardner and Demar, 2013)

Sirenidae

Habrosaurus sp. (in Gardner and Demar, 2013)

Anura

Family incertae sedis

Scotiophryne pustulosa (in Gardner and Demar, 2013)

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Theatonius sp. (in Gardner and Demar, 2013)
 cf. *Eopelobates* sp. (in Gardner and Demar, 2013)
 Gen. and sp. indet. (in Roček and others, 2010; Roček and others, 2013)

Scincomorpha

Borioteiioidea

Peneteius saueri (in Nydam, 2013)
Meniscognathus molybrochorus (Nydam and Voci, 2007)
Chamops sp. cf. *C. segnis* (in Nydam, 2013)
 cf. *Leptochamops* sp. (in Nydam and Voci, 2007)
Trippennaculus eatoni (in Nydam and Voci, 2007)

Contogeniidae

Palaeoscincosaurus pharkidodon (Nydam and Fitzpatrick, 2009)

Paramacelolidid/Cordylid Grade

Morphotype A-G (in Nydam, 2013)

Anguimorpha

Anguidae

Odaxosaurus roosevelti (in Nydam, 2013)

Xenosauridae

?*Exostinus* sp. (in Nydam, 2013)

Platynota

Family incertae sedis

Parasaniwa cynochoros (Nydam, 2013)
 Morphotypes H-J (in Nydam, 2013)

Serpentes

Family incertae sedis

Coniophis sp. (in Nydam, 2013)

Testudines

Pleurosternidae

Compsemys victa (in Hutchison and others, 2013)

Baenidae

Neurankylus hutchisoni (Lively, 2015b; new sp. A in Hutchison and others, 2013)
Neurankylus utahensis (Lively, 2015b; new sp. B in Hutchison and others, 2013)
Arvinachelys goldeni (Lively, 2015a)
Denazinemys nodosa (in Hutchison and others, 2013; Lively, 2015b)
Boremys grandis (in Hutchison and others, 2013; Lively, 2015b)
Plesiobaena sp. (in Hutchison and others, 2013)
Thescelus sp. (Lively, 2015b)

Chelydridae

Gen. and sp. indet. (in Hutchison and others, 2013)

Kinosternidae

Gen. and sp. indet. (in Hutchison and others, 2013)

Adocidae

Adocus sp. (in Hutchison and others, 2013)

Nanhsiungchelyidae

Basilemys nobilis (in Hutchison and others, 2013)

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Tritychidae

- Helopanoplia* sp. (in Hutchison and others, 2013)
- Aspideretoides* sp. (in Hutchison and others, 2013)
- Derrisemys* sp. (in Hutchison and others, 2013)
- Plastomenoides* sp. (in Hutchison and others, 2013)
- Gen. and sp. indet. (in Hutchison and others, 2013)

Crocodylia

Neosuchia

- cf. *Denazinasuchus* sp.
- Alligatoroidea Family incertae sedis
 - cf. *Leidyosuchus* sp. (in Farke and others, 2014)
 - Deinosuchus hatcheri* (in Irmis and others, 2013)
 - Brachychamps* sp. (in Irmis and others, 2013)

?Pterosauria

- Gen. and sp. indet (in Farke and others, 2013)

Dinosauria-Saurischia

Theropoda-Ornithomimidae

- Ornithomimus* sp. indet. (in Claessens and Loewen, 2015)

Oviraptoridae

- Hagryphus giganteus* (Zanno and Sampson, 2005)

Dromaeosauridae

- Morphotype A (cf. *Dromaeosaurus*) (in Zanno and others, 2013)
- Morphotype B (cf. *Saurornitholestes*) (in Zanno and others, 2013)

Troodontidae

- Talos sampsoni* (Zanno and others, 2011)

Aviales

- Avisaurus* sp. (in Zanno and others, 2013)

Tyrannosauridae

- Teratophoneus curriei* (Carr and others, 2011)

Dinosauria-Ornithischia

Hypsilophodontidae

- Gen and sp. nov. (in Boyd, 2015, “hypsilophodontid” in Gates and others, 2013)

Hadrosauridae-Saurolophinae

- Gryposaurus* cf. *G. notabilis* (in Gates and others, 2013)
- Gryposaurus monumentensis* (Gates and Sampson, 2007)

Hadrosauridae-Lambeosaurinae

- Parasaurolophus* sp. (in Gates and others, 2013)

Ceratopsidae-Chasmosaurinae

- Utahceratops gettyi* (Sampson and others, 2010)
- Kosmoceratops richardsoni* (Sampson and others, 2010)

Ceratopsidae-Centrosaurinae

- Nasutoceratops titusi* (Sampson and others, 2013)
- “Centrosaurine B” (in Loewen and others, 2013b)

Pachycephalosauridae (dome-headed dinosaurs)

- Gen. and sp. indet. (in Evans and others, 2013)

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- Nodosauridae (spike-tailed armored dinosaurs)
 - Gen. and sp. indet. (in Loewen and others, 2013a)
- Ankylosauridae
 - New genus and species A (in Viersma, 2015)
 - New genus and species B (in Viersma, 2015)
- Mammalia-Multituberculata
 - Family incertae sedis
 - Cimexomys* sp. cf. *C. judithae* (in Eaton, 2002)
 - Cimexomys* or *Mesodma* sp. (in Eaton, 2002)
 - Family incertae sedis – *Paracimexomys* group
 - Cedaromys hutchisoni* (in Eaton, 2002)
 - Cedaromys* sp. (in Eaton, 2002)
 - Dakotamys magnus* (in Eaton, 2002)
 - Neoplagiulaclidae*
 - Mesodma archibaldi* (in Eaton, 2002)
 - Mesodma* sp. cf. *M. archibaldi* (in Eaton, 2002)
 - Mesodma minor* (in Eaton, 2002)
 - Mesodma* sp. (large) (in Eaton, 2002)
 - Cimolodontidae*
 - Cimolodon foxi* (in Eaton 2002)
 - Cimolodon* sp. cf. *C. nitidus* (in Eaton, 2002)
 - Cimolodon* sp. cf. *C. similis* (in Eaton, 2002)
 - ?*Cimolodontidae*
 - Kaiparomys cifellii* (in Eaton, 2002)
 - Cimolomyidae*
 - Meniscoessus* sp. cf. *M. intermedius* (in Eaton, 2002)
 - Meniscoessus* sp. cf. *M. major* (in Eaton, 2002)
 - Cimolomys* sp. A cf. *C. clarki* (in Eaton, 2002)
 - Cimolomys* sp. B cf. *C. clarki* (in Eaton, 2002)
 - ?*Cimolomyidae*
 - ?*Cimolomys butleria* (in Eaton, 2002)
 - Marsupialia*
 - Family incertae sedis
 - Aenigmadelphys archeri* (in Cifelli, 1990d; Cifelli and Johanson, 1994)
 - “*Alphadontidae*”
 - Varalphadon wahweapensis* (in Cifelli, 1990d)
 - Turgidodon lillegraveni* (in Cifelli, 1990d)
 - Turgidodon* sp. cf. *T. lillegraveni* (in Cifelli, 1990d)
 - Turgidodon madseni* (in Cifelli, 1990d)
 - Turgidodon* sp. (in Cifelli, 1990d)
 - Alphadon halleyi* (in Cifelli, 1990d)